XXVIII. *On the Motion of Gases.* *By* THOMAS GRAHAM, *Esq., F.R.S., Professor of Chemistry in University College, London; Hon. Fellow of the Royal Society of Edinburgh; Corresponding Member of the Royal Academies of Sciences of Berlin and Munich, of the National Institute of Washington, &c.*

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THE spontaneous intermixture of different gases, and their passage under pressure through apertures in thin plates and by tubes, form a class of phenomena of which the laws have been only partially established by experiment. The separation of two gases by a porous screen, such as a plate of dry stucco, will prevent for a short time any sensible intermixture arising from slight inequalities of pressure, but such a barrier is readily overcome by the diffusive power of the gases, which is fully equal to their whole elastic force. Hence a cylindrical glass jar with a stucco top, filled with any gas and standing over water, affords the means of demonstrating the unequal diffusive velocities of air and the gas, by the final contraction or expansion of the gaseous contents of the jar, after the escape of the gas is completed. Compared with the volume of air which has entered, the volume of gas which has passed simultaneously outwards is found to be in the inverse proportion of the square root of the specific gravity of the gas. The diffusive velocities therefore of different gases are inversely as the square root of their densities; or the times of diffusion of equal volumes directly as the square root of the densities of the gases*.

Such is also the theoretical law of the passage of gases into a vacuum, according to the well-known theorem that the molecules of a gas rush into a vacuum with the velocity they would acquire by falling from the summit of an atmosphere of the gas of the same density throughout; while the height of such an atmosphere, composed of different gases, is inversely as their specific gravities. This is a particular case of the general law of the movement of fluids, well-established by observation for liquids, and extended by analogy to gases. The experiments which have already been made upon air and other gases, by M. P. S. GIRARD† and by Mr. FARADAY‡, are sufficient to show that the discharge of light is more rapid than that of heavy gases; and are interesting as first approximations, although incomplete and lending a very imperfect support to the theoretical law. Indeed some results obtained by these experimenters

* On the Law of the Diffusion of Gases; Transactions of the Royal Society of Edinburgh, vol. xii. p. 222; or Philosophical Magazine, 1834, vol. ii. pp. 175, 269, 351.

† Annales de Chimie, &c., 2de Sér., t. 16. p. 129.

‡ Quarterly Journal of Science, vol. iii. p. 354; and vol. vii. p. 106.

and others, appear wholly inconsistent with that law, such as Mr. FARADAY's curious observations of the change of the relative rates of hydrogen and olefiant gases in passing through a capillary tube under different pressures; and my own observation, that carbonic acid gas is forced by pressure through a porous mass of stucco as quickly or more so than air is, although more than a half heavier; and that other gases pass in times which have no obvious relation to their diffusive velocities*.

In studying this subject, I found that it was necessary to keep entirely apart the two cases of the passage of a gas through a small aperture in a thin plate and its passage through a tube of sensible length. The phenomena of the first class then became well-defined and simple, and quite agreeable to theory. Those of the second class also attained a high degree of regularity, where the tubes were of great length, or being short were of extremely small diameter. Capillary glass tubes, which varied in length from twenty feet to two inches, were found equally available and gave similar results, where a sufficient resistance was offered to the passage of the gas.

The rate of discharge of different gases from capillary tubes appears to be independent of the nature of the material of the tube, in so far as the rates were found to be similar for tubes of glass and copper, and even for a porous mass of stucco. But while the discharge by apertures in thin plates is found to be dependent in all gases upon a constant function of their specific gravity, the discharge of the same gases from tubes has no uniform relation to the density of the gases. Both hydrogen and carbonic acid, for instance, pass more quickly through a tube than oxygen, although the one is lighter and the other heavier than that gas. I shall assume then for the present, that in the passage of gases through tubes we have the interference of a new and peculiar property of gases; and on the ground of a radical difference in agency speak of the two classes of phenomena under different names. The passage of gases into a vacuum through an aperture in a thin plate I shall refer to as the *Effusion* of gases, and to their passage through a tube as the *Transpiration* of gases. The determination of the coefficients of effusion and transpiration of various gases will be the principal object of the following paper.

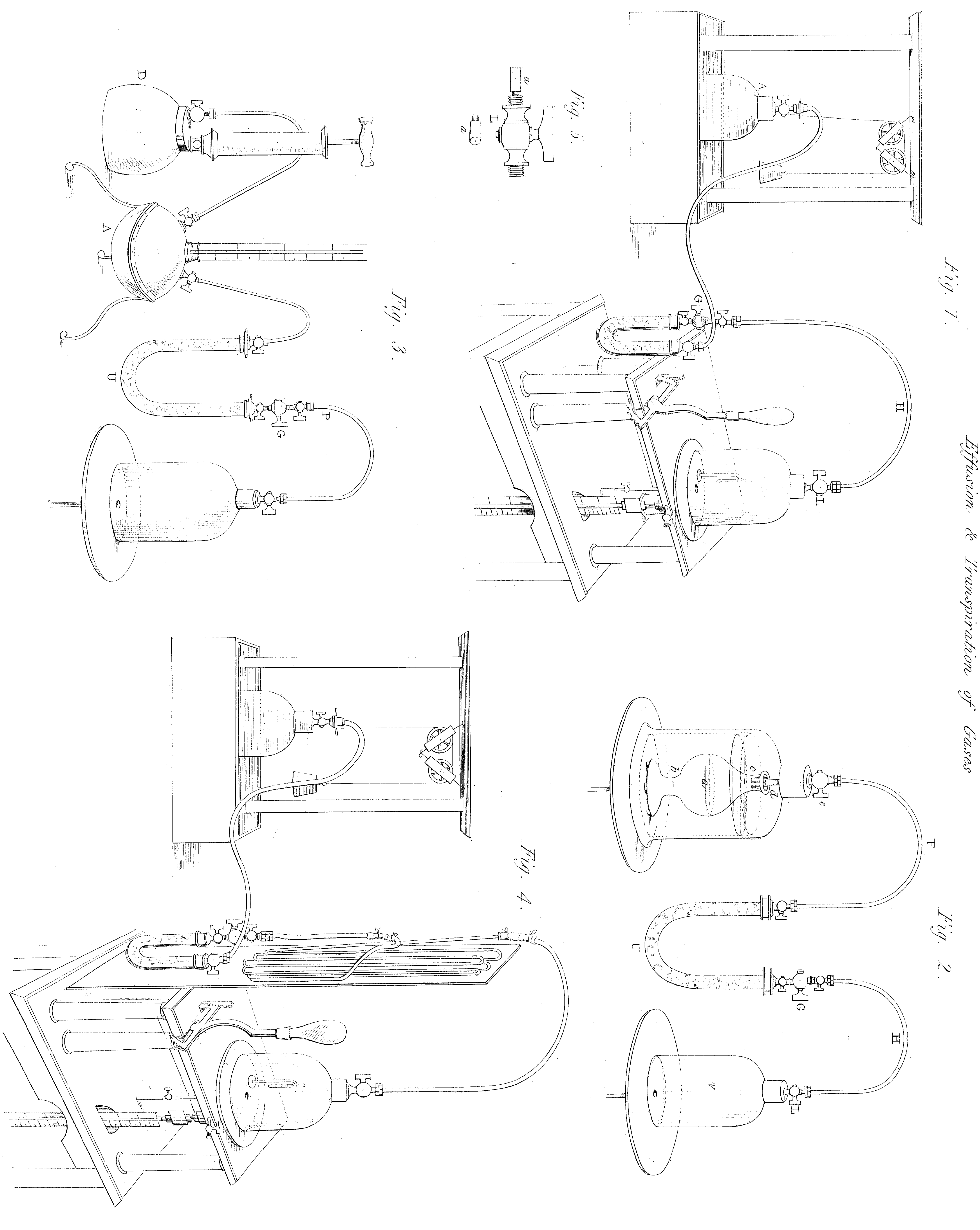
PART I.—EFFUSION OF GASES.

1. *Effusion into a Vacuum by a glass jet.*

The glass jet was formed from a short piece of a capillary thermometer tube, of which the bore was cylindrical, to which a conical termination was given by drawing it out when softened by heat and breaking the point. The aperture at the point of the jet was cylindrical, in a flat surface, and so small that it could only be seen distinctly by means of a magnifying-glass; its size, compared with other apertures, may be expressed by the statement that one cubic inch of air of the usual tension passed into a vacuum through this aperture in 2·18 seconds. By means of a perforated

* Edinburgh Transactions, xii. 238.

Effusion & Transpiration of Gases



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cork this glass jet was fixed within a block-tin tube, through which the gas was to be drawn; with the point of the tube directed towards the magazine of gas, so that the gas in passing towards the vacuum entered the conical point of the jet instead of issuing from it. This form of the aperture reduced the rubbing surface of glass to a thin ring, or made it equivalent to an aperture in a very thin plate; but the mode of placing the jet, or direction in which the current passed through the aperture, was found afterwards to be of little consequence.

The gas for an experiment was contained in a glass jar, of an elliptical form, balanced like a gasometer over water, and terminated at top and bottom with two short hollow cylindrical axes, of an inch in diameter; its capacity between two marks, one on each of the cylindrical ends, being 227 cubic inches. From this gasometer the gas was conveyed directly into a U-shaped drying tube, 18 inches in length and 0·8 inch in diameter, filled in some cases with fragments of chloride of calcium, in others with fragments of pumice-stone soaked in oil of vitriol; the pumice, when used, having been first washed with water, to deprive it of soluble chlorides. From the drying tube, the gas entered the tin tube occupied by the glass jet, one end of that tube being connected with the drying tube, and the other with an exhausted receiver on the plate of an air-pump. The apparatus described is exhibited in fig. 1 of Plate XXXIII., with the exception of the elliptical gasometer, the place of which is occupied there by the counterpoised jar A in the water-trough. The gas was thus forced through the minute aperture by the whole atmospheric pressure. In making an experiment with any other gas than atmospheric air, a considerable quantity of the gas was first blown through the drying tube, from the gasometer, to displace the air in the former; and to do this quickly an opening was made into the air-channel beyond the drying tube, at G, by which gas might be allowed to escape into the atmosphere without proceeding further or being drawn through the glass aperture into the vacuum. This side aperture was closed by a brass screw and leather washer. In making an experiment, the gasometer was filled with the gas to be effused, and then connected with the air-pump receiver, in which a constant degree of exhaustion was maintained by continued pumping. The interval of time was noted in seconds, which was required for the passage of a constant volume of gas, amounting to 227 cubic inches, namely, that contained between the two marks in the elliptical gasometer. Or, the volume of gas effused was more strictly 227 cubic inches, minus the volume of aqueous vapour which saturates air at the temperature of the experiment; the vapour being withdrawn from the gas, after it left the elliptical measure and before it reached the effusion aperture. It is scarcely necessary to add that great care is necessary during these and all other experiments on gases, to maintain a uniform temperature. The use of a fire or stove in the room in which the experiments were conducted was therefore avoided, and such arrangements made that the temperature was kept for five or six hours within a range of a single degree of FAHRENHEIT's scale.

Hydrogen.—In the experiments first made with air and hydrogen the temperature

was 59° FAHR., and the height of the barometer 30·14 inches; a uniform exhaustion was maintained in the air-pump receiver of 29·3 inches, as observed by the gauge barometer attached.

The constant volume of dry air passed into the vacuum, or was effused, in three experiments, in 494, 495, and again in 495 seconds.

The constant volume of dry hydrogen was effused, in two experiments, in 137 and again in 137 seconds. Calculating from 495 seconds as the time for air, we have—

Time of effusion of air	1·
Time of effusion of hydrogen	0·277

Or, the result may be otherwise expressed, taking the reciprocals of the last numbers:

Velocity of effusion of air	1
Velocity of effusion of hydrogen	3·613

The specific gravity of hydrogen gas, according to the most recent and exact determination, that of REGNAULT, is 0·06926, referred to air as unity; of which the square root is 0·2632, and the reciprocal of the square root 3·7994; to which the numbers for the time and velocity of hydrogen above certainly approximate.

Oxygen and Nitrogen.—Temperature 60°; exhaustion maintained at 29·3 inches. The constant volume of air was effused in 494 seconds, of oxygen in 520 seconds, and of nitrogen in 486 seconds, in one experiment made upon each gas. Hence the following results:

	Time of effusion.	Square root of density.	Velocity of effusion.	Reciprocal of square root of density.
Air	1	1	1	1
Oxygen	1·053	1·0515	0·9500	0·9510
Nitrogen........................	0·984	0·9856	1·0164	1·0146

The densities made use of are those of M. REGNAULT, namely, 1·10563 for oxygen, and 0·97137 for nitrogen. It will be observed, that the times of effusion of these two gases correspond as closely with the square roots of their densities as the mode of observation will admit of; the times observed being within one second of the theoretical times.

Carbonic Oxide.—This gas was prepared by the action of oil of vitriol upon pure crystallized oxalic acid, and subsequent washing with alkali. The temperature during the effusive experiment was 60°·3; the usual exhaustion was maintained. The time of effusion of air was 494 seconds; of the same volume of carbonic oxide 488 seconds:

	Time of effusion, air = 1.	Square root of density.	Velocity of effusion.	Reciprocal of square root.
Carbonic oxide	0·987	0·9838	1·0123	1·0165

The effusion-rate of this gas approaches therefore very closely to the theoretical number. In the calculations the density of carbonic oxide is taken at 0·96779, as found by WREDE.

Carburetted Hydrogen., CH_2.—This was the gas of the acetates, prepared by heating a mixture of acetate of soda with dry hydrate of potash and lime.

The temperature of the gases effused being 59°·5, and the exhaustion 29·3 inches; the constant volume of air passed through the aperture in 493 seconds, of carburetted hydrogen in 373 seconds:

	Time, air =1.	Theoretical time.	Velocity.	Theoretical velocity.
Carburetted hydrogen	0·756	0·7449	1·322	1·3424

The density of carburetted hydrogen is taken at 0·5549 in the calculations.

Carbonic Acid and Nitrous Oxide.—In the first experiment with carbonic acid, the gasometer with the gas was floated as usual over water; thermometer 58°·5. The effusion of air took place in 495 seconds, of carbonic acid in 595 seconds. To diminish the loss of the latter gas occasioned by its solubility in water, a second experiment was made over brine: the time required by the carbonic acid was now 603 seconds. The velocity of effusion of carbonic acid is by the first experiment 0·832; by the second it approaches more nearly the theoretical number, calculated from 1·52901 (REGNAULT) as the density of this gas, as appears below:

	Time, air =1.	Theoretical time.	Velocity.	Theoretical velocity.
Carbonic acid.................	1·218	1·2365	0·821	0·8087

The observation on nitrous oxide was made on a different occasion, with a temperature of 62°·5. The time of effusion of air was then 488 seconds; of nitrous oxide 585 seconds, the gas being collected over water:

	Time, air =1.	Theoretical time.	Velocity.	Theoretical velocity.
Nitrous oxide.................	1·199	1·2365	0·834	0·8087

The specific gravity of nitrous oxide is assumed in the calculations to be the same as that of carbonic acid. The time of effusion of both of these gases is shortened by the loss of a portion of the gas, by solution in the water of the pneumatic trough during the period of the experiment, and falls below the theoretical number. In carbonic acid over brine, where the injury is least from this cause, the observed velocity is, however, still within one-seventieth part of that calculated from the specific gravity of the gas.

Olefiant Gas.—When this gas is prepared by heating sulphuric acid, of specific gravity 1·6, with strong alcohol at the temperature of 320°, in the proportion of six parts of the former to one of the latter, it appears to come off at first very pure, as it is entirely absorbed by the perchloride of antimony, and contains therefore no carbonic oxide. But it is really contaminated, I find, by a portion of another heavier gas or vapour (not ether vapour), which cannot be entirely removed from it by washing with alkaline water, oil of vitriol, or strong alcohol, and which may raise the density of the gas above that of air. As the evolution of gas proceeds, the proportion of the heavy compound diminishes, and it finally disappears, and the gas attains its theoretical density; but it is then again contaminated with more or less carbonic oxide. The latter gas, however, being of sensibly the same density as olefiant gas, is not likely to exert any influence upon its effusion rate. But before these facts were ascertained this jet became unserviceable from an accident, and the experiments made with it were all made upon the dense olefiant gas, and gave an effusion time which slightly exceeded that of air.

2. *Effusion into a Vacuum by a perforated brass plate* A.

A minute circular aperture was made by means of a fine drill in a thin plate of sheet brass $\frac{1}{228}$th of an inch thick, and the opening still further diminished by blows from a small hammer, of which the surface was rounded. A small disc of the brass plate was then punched out, having the aperture in the centre, which was soldered upon the end of a short piece of brass tube, of quill size, so as to close the end of the cylinder. This brass tube was then fixed, by means of a perforated cork, within the tin tube, used as formerly, for conveying the gas from the gasometer jar to the air-pump receiver; so that the gas should necessarily flow through the small aperture in its passage, as before through the glass jet. The aperture was of an irregular triangular form, in consequence of the hammering of the plate. One cubic inch of air of usual tension passed into a vacuum through this aperture in 12·56 seconds. The volume of gas effused in an experiment was the same as before, and the other arrangements similar, but the aperture in the brass plate being smaller than that of the glass jet, the effusion was considerably slower.

The constant volume of 227 cubic inches of the following gases passed into a vacuum of 29·3 inches by the attached mercurial gauge, at the temperature of 63°·3, in the following times:—

(1.) Air in 47′ 32″, or 2852 seconds.
(2.) Nitrogen in 46′ 47″, or 2807 seconds.
(3.) Oxygen in 50′ 1″, or 3001 seconds.
(4.) Hydrogen in 13′ 8″, or 788 seconds.
(5.) Carbonic acid (over brine) in 56′ 54″, or 3414 seconds.

These results, referred to air as unity, are as follows:—

	Time of effusion.	Theoretical time.	Velocity of effusion.	Theoretical velocity.
Air	1	1	1	1
Nitrogen	0·9842	0·9856	1·0160	1·0146
Oxygen	1·0502	1·0515	0·9503	0·9510
Hydrogen	0·2763	0·2632	3·607	3·7994
Carbonic acid	1·1971	1·2365	0·8354	0·8087

The experimental results of the velocity of effusion of nitrogen and oxygen accord very closely with theory, the velocity of the first being only 0·0014 in excess, and the second 0·0007 in deficiency. Indeed the differences fall within the unavoidable errors of observation in determining the specific gravity of these gases, unless conducted with the greatest precautions. Of hydrogen, the velocity of effusion observed is 3·607 times instead of 3·80 times greater than air. It thus suffers a small but sensible reduction of its velocity, which can be referred, as will afterwards appear, to the thickness of the plate and the aperture being in consequence sensibly tubular. A portion of the carbonic acid gas must have been absorbed by the brine during the long continuance of the experiment, nearly an hour; to which the quickness of the rate of that gas may be referred; the velocity of its passage being thus apparently increased from 0·81 to 0·835.

The experiment was varied by observing the time in which gas entered a vacuous receiver upon the plate of the air-pump, in quantity sufficient to depress the gauge barometer from 28 to 23 inches. An exhaustion was always made at first of upwards of 29 inches, and the instant noted at which the mercury passed the 28th and 23rd inches of the scale. The times of effusion were as follows, the temperature being 66°.

	Experiments.				Velocity of effusion.	
	1.	2.	3.	Mean.	Observed.	Calculated.
Air	474	474	....	474	1	1
Oxygen	501	502	499	500·7	0·9467	0·9510
Nitrogen	468	469	....	468·5	1·0117	1·0146
Olefiant gas	467	469	....	468	1·0128	1·0147
Carburetted hydrogen	357	....	....	337	1·3278	1·3369
Carbonic acid	573	573	....	573	0·8272	0·8087

The same close correspondence is manifest here between the observed and calculated velocities.

The whole results leave no doubt of the truth of the general law, that *different gases pass through minute apertures into a vacuum in times which are as the square roots of their respective specific gravities; or with velocities which are inversely as the square roots of their specific gravities;* that is, according to the same law as gases diffuse into each other.

It appears that the proper effect of effusion can only be brought out in a perfect

manner when the gas passes through an aperture in a plate of no sensible thickness, for when the opening becomes a tube, however short, the effluent gas meets a new resistance which varies in the different gases according to an entirely different law from their rates of effusion, namely, the resistance of transpiration. The deviation is most considerable in hydrogen, which rapidly loses velocity if carried through a tubular opening, when compared with air. This was illustrated by experiments made upon the glass jet of the former observations; which was operated upon in four different conditions as to length. The point had been drawn out rather long at first, so that it admitted of portions of 0·2 inch, 0·1 inch, and 0·07 inch, being broken off successively before it was reduced to the form of a blunt cone, which it had when used in the experiments already detailed. Air and hydrogen were effused from this jet into the exhausted receiver till the mercurial gauge fell from 28 to 4 inches, with the jet in the different states described.

When the glass jet was of greatest length, the time of air was 335 and 337 seconds in two experiments, and of hydrogen 120 seconds in two experiments; which give 2·800 as the velocity of effusion of hydrogen.

After the first portion was broken from the point, by which of course the aperture was enlarged, the time of air was 175 seconds in two experiments, of hydrogen 55 and 56 seconds; giving 3·153 for the effusive velocity of hydrogen.

After the second abridgement in its length, the time of passage of air by the jet was 110 seconds in two experiments, of hydrogen 33, 32 and 33 seconds in three experiments; giving 3·33 for the velocity of hydrogen.

When still further reduced in length, a larger jar being used as the vacuous receiver, the time of air was in two experiments 408 and 410 seconds; of hydrogen in three experiments, 122, 120 and 122 seconds, giving 3·38 for the velocity of hydrogen. Thus, as the jet was progressively shortened, the relative velocity of the passage of hydrogen continually rose, passing through the numbers 2·8, 3·153, 3·33 and 3·38. By reversing the direction of the stream of gas through the aperture in its last condition, the effect of friction was still further diminished, and the velocity of hydrogen raised to 3·61, as in the experiments previously recorded, which were made with this jet in an inverted position. It may be fairly presumed, therefore, that if the length of the tube or thickness of the plate containing the aperture was still further diminished, the effusive velocity of hydrogen, compared with air, would be increased, and approximate more nearly to 3·80, the theoretical number.

The tubularity of the opening quickens, on the contrary, the passage of carbonic acid and nitrous oxide in reference to air; for these gases are more transpirable than air, although less effusive: hence their observed time of effusion is always sensibly less than their calculated time.

3. *Effusion of Nitrogen and Oxygen, and of mixtures of these Gases under different pressures, by a second perforated brass plate* B.

This brass plate was of the same thickness as the last ($\frac{1}{228}$th of an inch); the aperture was circular and also $\frac{1}{228}$th of an inch in diameter, as measured by a micrometer; and the velocity with which air of the usual tension passed into a vacuum by the aperture, one cubic inch in 6·08 seconds. The rate of passage was therefore rather more than twice as quick as by the first perforated plate A.

A two-pint jar was used as the air-pump receiver, or aspirator-jar, as it may be called; and the capacity of the vacuous space into which the gas effuses, including the tubes and channels of the air-pump as well as the jar, was found to be 72·54 cub. in. An exhaustion was always first made of about 29 inches by the gauge barometer of the pump, and then the gas allowed to enter from a counterpoised bell-jar over water (fig. 1, Plate XXXIII.). The instant was noted at which the mercury fell to 28 inches, when the observation began, and again at 20 and 12 inches, or after two intervals of 8 inches each; and again at 4 and 2 inches by the gauge barometer. The experiments were made successively on the same day in the order given, with the barometer at 29·34 inches and thermometer at 49°. A small thermometer placed within the aspirator-jar was observed to rise 1° FAHR. very uniformly during the continuance of an experiment. The effusion of air is repeated at the close of the experiments to determine whether or not any change of rate had occurred during their continuance.

TABLE I.—Effusion.

Gauge barometer in inches.	Air.		Nitrogen.		Oxygen.		Mixture of 50 nitrogen + 50 oxygen.	
	I.	II.	I.	II.	I.	II.	I.	II.
28	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0
20	120	120	119	119	126	126	122	122
12	123	122	120	120	128	130	125	125
8	68	68	67	67	72	72	70	69
4	84	84	83	83	89	88	85	86
2	57	57	55	54	59	59	57	57
	452	451	444	444	474	475	459	459

TABLE II.—Effusion.

Gauge barometer in inches.	25 nitrogen + 75 oxygen.		75 nitrogen + 25 oxygen.		Air.
	I.	II.	I.	II.	
28	″ 0	″ 0	″ 0	″ 0	″ 0
20	122	122	122	121	120
12	125	125	122	122	123
8	70	69	68	68	68
4	85	86	85	85	83
2	57	57	56	56	57
	459	459	453	453	451

The near approach to equality in the times from 28 to 20, and from 20 to 12 inches throughout the whole of these experiments, is very remarkable. Under an average pressure of 24 inches in the former portion of the scale and of 16 in the latter, the gases effuse with nearly equal velocities; which confirms the observation of MM. De Saint-Venant and Wantzel, on the passage of air through a minute aperture, namely, that above two-fifths of an atmosphere, the further increase of the pressure is attended with a very slight increase in the velocity of passage*. In the experiments above with an increase of pressure from 16 to 24, or of one-half, the increase in velocity is not in general more than one-sixtieth part.

In the table which follows the average times are given, which the gauge barometer required to fall from 28 to 12 inches, and from 12 to 4 inches, taken from the preceding table, for air, nitrogen and oxygen, and also the ratio between the times of these gases, that of air being taken as unity, with their relative velocities, also referred to the velocity of air.

Gauge barometer.	Time in seconds.			Time of air = 1.		Velocity of air = 1.	
	Air.	Nitrogen.	Oxygen.	Nitrogen.	Oxygen.	Nitrogen.	Oxygen.
From 28 to 12 inches.	242·5	239	255·0	0·9855	1·0515	1·0146	0·9510
From 12 to 4 inches.	152·0	150	160·5	0·9868	1·0558	1·0133	0·9470

These results do not indicate any material difference between the ratios of effusion of these gases at different pressures. At the low as well as the high pressure, the velocities are in close accordance with the law of effusion; indeed they correspond as closely as the shortness of the time of observation justifies any inference; the small deviations observable being quite within the amount of errors of observation.

The results for the mixtures of oxygen and nitrogen are as follows, for similar divisions of the scale:—

Gauge barometer.	Time in seconds.			Time, air = 1.		
	I. 50 N + 50 O.	II. 25 N + 75 O.	III. 75 N + 25 O.	I. Mixture.	II. Mixture.	III. Mixture.
From 28 to 12 inches.	247	252	243·5	1·0185	1·0391	1·0041
From 12 to 4 inches.	155	157	153	1·0197	1·0329	1·0066

In these instances, as well as in the unmixed gases, the results do not justify the inference of any difference in the ratios of effusion at low from the ratios which hold at high pressures.

It appears, on comparing the times observed of the mixtures with the times calculated from the unmixed gases, that they sensibly agree. Thus the mean rate or time

* Journal de l'Ecole Royale Polytechnique, tome xvi. 27me Cahier, 1839, p. 85. This memoir contains a valuable mathematical discussion of the velocities with which air flows into a receiver at different degrees of exhaustion.

of 50 nitrogen + 50 oxygen, or square root of the specific gravity of that mixture, is 1·0191, the observed rate 1·0185; of 25 nitrogen + 75 oxygen, the mean rate is 1·0354, the observed rate 1·0391; of 75 nitrogen + 25 oxygen, the mean rate is 1·0025, the observed time 1·0041, in the range between 28 and 12 inches of the gauge barometer. Lastly, the particular mixture forming atmospheric air has already been seen to have the rate corresponding with its specific gravity or its composition. It may hence be inferred that any mixture of oxygen and nitrogen will possess the average rate of effusion of its constituent gases.

4. *Effusion of Air, Carbonic Oxide, Oxygen, and of a mixture of Carbonic Oxide and Oxygen at different pressures, by Plate* B.

The carbonic oxide was prepared according to Mr. Fownes's process, by heating oil of vitriol upon ferrocyanide of potassium: the gas was collected, as a measure of precaution, over alkali.

The arrangements were similar to the last; barometer at 29·29 inches, thermometer 52°.

Table III.—Effusion.

Gauge barometer in inches.	Air.		Carbonic oxide.		Oxygen.		Mixture of 50 carbonic oxide + 50 oxygen.	
	I.	II.	I.	II.	I.	II.	I.	II.
28	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0
20	118	119	116	117	125	126	121	121
12	120	120	118	117	126	126	123	122
8	67	66	66	66	71	71	68	68
4	81	82	80	81	86	86	83	83
2	56	56	55	55	60	60	58	58
	442	443	435	436	468	469	453	452

The passage of the gases is somewhat quicker throughout than in the preceding experiments with the same plate, but the ratio between their velocities remains constant.

Comparing again the same portions of the scale, we have—

Gauge barometer.	Time in seconds.				Time, air = 1.		
	Air.	Carbonic oxide.	Oxygen.	Mixture.	Carbonic oxide.	Oxygen.	Mixture.
From 28 to 12 inches	238·5	234	251·5	243	0·9811	1·0545	1·0188
From 12 to 4 inches	148	146·5	157	151	0·9898	1·0608	1·0202

Taking 0·96779 as the specific gravity of carbonic oxide, the square root is 0·9838, which corresponds closely with the observed time above, being intermediate between the times for the two different portions of the scale.

The time of effusion also of the mixture of carbonic oxide and oxygen in equal volumes is obviously the square root of the density of the mixture of the two gases:

Observed time of mixture . . . . 1·0188
Calculated time of gases . . . . 1·0182

The observed time of effusion of the mixture being within one thousandth part of the calculated time.

5. *Effusion of Carbonic Acid, Air, and of mixtures of Carbonic Acid and Air, at different pressures, by Plate* B.

The arrangements continued the same as in last experiments; barometer 29·58 in.; thermometer 49°.

TABLE IV.—Effusion.

Gauge barom. in inches.	Air.		Carbonic acid.		First mixture, $75CO_2+25$ air.		Second mixture, $50CO_2+50$ air.		Third mixture, $25CO_2+75$ air.	
	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.
	"	"	"	"	"	"	"	"	"	"
28	0	0	0	0	0	0	0	0	0	0
20	121	121	145	146	141	140	135	134	128	128
12	123	123	150	149	143	143	137	137	131	131
8	69	70	83	84	81	80	76	77	74	73
4	85	84	103	103	98	99	95	94	90	90
2	58	59	71	70	68	67	64	64	61	61
	456	457	552	552	531	529	507	506	484	483

Comparing again the times in the two divisions of the scale adopted in the preceding tables:

Time in Seconds.

Gauge barometer.	Air.	Carbonic acid.	Mixture I.	Mixture II.	Mixture III.
From 28 to 12 inches.	244	295	283·5	271·5	259
From 12 to 4 inches.	154	187	179	171	163·5

Time of Effusion, time of Air $=1$.

Gauge barometer.	Carbonic acid.		Mixture I.		Mixture II.		Mixture III.	
	Observed.	Calculated.	Observed.	Calculated.	Observed.	Calculated.	Observed.	Calculated.
From 28 to 12 inches.	1·2090	1·2365	1·1618	1·1818	1·1127	1·1245	1·0618	1·0647
From 12 to 4 inches.	1·2143	1·2365						

The calculated number for carbonic acid (1·2365) is the theoretical time, or square root of the density of the gas; the calculated times for the mixtures are also the square roots of the respective gravities of those mixtures.

The times of effusion of carbonic acid compared with air do not therefore differ

more than the numbers 1·209 and 1·214, in the two divisions of the scale; or 1 part in 242, a deviation which may be considered as within the errors of observation.

The mixtures of carbonic acid and air have also the mean times of the pure gases.

6. *Effusion of mixtures containing Hydrogen.*

* [I was induced to examine the effusion of mixtures of hydrogen and other gases very minutely, in order to elucidate if possible certain singular peculiarities which were observed in the transpiration of these mixtures by tubes. A new plate E was employed, composed of thin platinum foil $\frac{1}{765}$th of an inch in thickness, with a circular aperture $\frac{1}{260}$th of an inch in diameter, as measured by Mr. POWELL by means of a micrometer. It was desirable to simplify the experiment at the same time by operating upon a constant volume of gas, measured before effusion, and drawn into an aspirator-jar which was maintained vacuous, or as nearly so as possible, by uninterrupted exhaustion. The gas was measured in a globular jar, to which more particular reference will be made hereafter. It contained 65 cubic inches between two marks, one upon each of its tubular axes, and was supported vertically over the water of a pneumatic trough.

The little brass tube upon which the perforated plate is fixed (*a.* in fig. 5, Plate XXXIII.) was now made to screw upon the end of one of the stop-cocks, namely, L (fig. 1.), which is immediately attached to the aspirator-jar, and projected upwards within the block tin tube H. The perforated plate was fixed to the end of its brass tube by means of soft solder.

The results thus obtained I consider superior in value to those already detailed, from the longer periods of observation, the time for air generally amounting to 800 or 900 seconds; from the new plate being thinner and its aperture of a regular circular form; and from the greater simplicity of the conditions of the experiment, namely, the passage of the gases into a sustained vacuum under the whole atmospheric pressure.

The series of experiments is divided into five sections, each containing the experiments of one day, to which the height of the barometer and the temperature are added. Two observations were made of the time of effusion in seconds for each gas, which are given under the columns of experiments I. and II., and the mean of the two experiments is added in a third column. This mean is expressed in the column which follows, with reference to the time of oxygen as 1. The additional column headed "calculated times of mixtures, oxygen = 1," contains times of the mixtures, calculated from their specific gravities, being the square roots of the densities of the respective mixtures. The observed times of the hydrogen mixtures will be seen to correspond very closely with these calculated numbers, the maximum divergences not exceeding that of pure hydrogen itself.

* The passages and tables in this paper, which are inclosed in brackets, as the following to p. 587, have been added during the progress of the paper through the press, and the date of the addition is in each case noted at the end of the last paragraph.—S. H. C.

TABLE V.—Effusion into a sustained vacuum by platinum plate E.

	I.	II.	Mean.	Oxygen=1.	Cal. time, Oxygen=1.	Barometer.	Temp. Fahr.
SECTION I.							
Oxygen	909	909	909	1·0000	....	30·396	68°
Air	866	865	865·5	0·9521			
Hydrogen	242	242	242	0·2662			
Carburetted hydrogen	624	622	623	0·6853			
Carbonic oxide	849	850	849·5	0·9345			
Nitrogen	850	851	850·5	0·9356			
Air	864						
Carbonic acid	1053	1051	1052	1·1573			
SECTION II.							
Oxygen	912	912	912	1·0000	....	30·288	66
Air	868	867	867·5	0·9512			
Hydrogen	240	240	240	0·2631			
25H+75 Air	756	756	756	0·8289	0·8328		
50H+50 Air	633	633	633	0·6940	0·6951		
75H+25 Air	483	483	483	0·5296	0·5224		
80H+20 Air	444	444	444	0·4868	0·4805		
90H+10 Air	358	358	358	0·3925	0·3830		
95H+ 5 Air	309	309	309	0·3388	0·3296		
Air	864						
SECTION III.							
Oxygen	912	910	911	1·0000	....	30·219	66
Air	867	865	866	0·9506			
Hydrogen	239	241	240	0·2634			
12·5H+87·5O	853	855	854	0·9374	0·9396		
25 H+75 O	796	796	796	0·8737	0·8750		
37·5H+62·5O	733	733	733	0·8046	0·7990		
50 H+50 O	661	661	661	0·7255	0·7289		
62·5H+37·5O	586	586	585·5	0·6427	0·6435		
75 H+25 O	501	501	501	0·5499	0·5449		
80 H+20 O	460	461	460·5	0·5055	0·5000		
90 H+10 O	368	368	368	0·4039	0·3954		
95 H+ 5 O	312	312	312	0·3424	0·3309		
Air	860						
SECTION IV.							
Oxygen	914	913	913·5	1·0000	....	29·673	64
Air	870	869	869·5	0·9518			
Carbonic oxide	854	853	853·5	0·9343			
Hydrogen	238	239	238·5	0·2610			
25H+75CO	749	748	748·5	0·8193	0·8199		
50H+50CO	626	626	626	0·6852	0·6848		
75H+25CO	478	478	478	0·5231	0·5155		
80H+20CO	445	445	445	0·4871	0·4745		
90H+10CO	360	360	360	0·3940	0·3793		
95H+ 5CO	314	314	314	0·3437	0·3213		
Air	870						
SECTION V.							
Oxygen	915	914	914·5	1·0000	....	29·500	63
Air	870	869	869·5	0·9508			
Nitrogen	855	854	854·5	0·9344			
Hydrogen	241	241	241	0·2635			
25H+75N	753	753	753	0·8234	0·8213		
50H+50N	631	631	631	0·6899	0·6859		
75H+25N	480	478	479	0·5238	0·5163		
80H+20N	442	442	442	0·4833	0·4752		
90H+10N	359	359	359	0·3925	0·3797		
95H+ 5N	309	310	309·5	0·3379	0·3215		
Hydrogen	241						
Air	869						

The principal results of the preceding table, and also the results of two series of experiments or mixtures of hydrogen with carburetted hydrogen ($C H_2$) and with carbonic acid, are exhibited by means of the curves projected in Plate XXXIV, for the purpose of comparing with them the results of the transpiration of the same mixtures exhibited in Plate XXXV, which I have not yet succeeded in reconciling with any physical law. Feb. 1846.]

The numbers at the top and bottom of the Plate, which apply to the vertical lines, express the times of effusion, the time of oxygen being taken as 100; while the numbers to the right of the table, and which apply to the horizontal lines, express the volumes of hydrogen in 100 volumes of the mixture. Thus the curves all terminate above in a common point, 26·3, the time of 100 hydrogen; and each terminates below with the proper time of the particular gas which is mixed with hydrogen, the proportion of hydrogen being then 0, and that of the other gas 100; that is, the curve of the carburetted hydrogen mixtures at 72·32; the curve of the nitrogen mixtures at 93·5; that of the air mixtures at 95·1; that of the oxygen mixtures at 100, and that of the carbonic acid mixtures at 116.

7. *Effusion of Air of different Elasticities or Densities, by brass plate* B.

In all the experiments hitherto described, the air or gas effused was under the atmospheric pressure, which varied only within narrow limits. It was desirable to know whether the time remained constant for the passage into a vacuum of equal volumes of air of all densities, which the theory of the passage of fluids into a vacuum requires.

The air was drawn into the receiver of an air-pump (fig. 2. Plate XXXIII.), maintained vacuous by continued pumping, from the globular gas receiver *a*, placed in a deep glass basin half-filled with water and used as a pneumatic trough; this basin and the globular vessel being placed on the plate of a second air-pump under a large bell-jar in which a partial exhaustion could be maintained during the continuance of the experiment. The vessel *a* had tubular openings at top and bottom; its capacity between the marks *b* and *c* in these necks was 65 cubic inches; the lower tube was expanded under the mark *b* into an open funnel; the upper tube was cylindrical with a flange or lip, and had a sound cork fitted into it. A short brass tube *d*, of quill size, soldered to the end of the stopcock *e*, descended into the bell-jar and passed through the cork of *a*, which was perforated. The vessel *a* having thus an air-tight communication with the exhausted receiver *v* of the first air-pump, by the tube F, the drying tube U and the tube H; a measured quantity of air (65 cubic inches) could be drawn from it by observing the time which the water of the trough took to rise from the mark *b* to *c*. The perforated brass plate, through which the gas had to pass, was attached to the stopcock L, as before, and was therefore within the tube H. It is represented of one-fourth of its linear dimensions in fig. 5, Plate XXXIII.

When the large bell-jar over *a* was not exhausted, the gas in the latter was of the atmospheric tension. With the barometer at 29·28 inches, and thermometer at 54°, the air was withdrawn from the globe *a*, in 388 seconds in one experiment, and in 389 seconds in another.

The pressure upon the air in *a* was then reduced to three-fourths of an atmosphere, by exhausting so that the gauge barometer stood at 7·32 inches from the bottom of the scale, which is one-fourth of the whole pressure of 29·28 inches. The globe *a* was thus occupied by air of the tension of three-fourths of an atmosphere, or 21·96 inches. It was in this state connected with the vacuous receiver *v* of the air-pump, and the time required for the effusion of the constant volume of 65 cubic inches of air, measured in its rarefied state, between the marks *b* and *c*, observed. The effusion of this volume of air of three-fourths density was effected in two experiments in 389 and 392 seconds.

Again, the air in *a* being made of 14·64 inches tension, or half an atmosphere, the constant volume was effused into a vacuum in 411 and 408 seconds.

Lastly, with the air in *a* of 7·32 inches tension, or one-fourth of an atmosphere, the time of effusion was 438 and 439 seconds. The results therefore of the effusion of a constant volume are as follows:—

	Time of effusion.	
Air of 1 atmosphere	388·5 seconds . . .	1.
Air of 0·75 atmosphere	390·5 seconds . . .	1·0051.
Air of 0·5 atmosphere	409·5 seconds . . .	1·0541.
Air of 0·25 atmosphere	438·5 seconds . . .	1·1287.

It thus appears that the effusion of air into a vacuum is very little affected by a moderate change of density; air of 1 atmosphere and of 0·75 atmosphere passing in nearly the same time. The effect therefore of the ordinary changes of the barometer on the effusion of air must be small, if at all sensible. A retardation occurs in the effusion of air of diminished density, which amounts to an excess of $\frac{1}{200}$th of the time, on air of 0·75 tension; of $\frac{1}{20}$th on air of 0·5 tension, and $\frac{1}{8}$th on air of 0·25 tension.

Experiments were also made on the effusion of air of higher density than 1 atmosphere. The air was drawn of any required tension from 1 to 2 atmospheres from a strong globular vessel A (fig. 3. Plate XXXIII.), provided with a gauge barometer and mercury, by which the tension of the compressed air within it was observed. Before its admission into this vessel the air was previously condensed in another vessel D by a syringe, to a higher degree of density than was required in A, and the supply of compressed air, regulated by the adjustment of an intermediate stopcock, so as to keep the gauge of A at a constant elevation, which could easily be done within $\frac{1}{20}$th of an inch.

In experiments with compressed air, the latter was allowed to flow into the two-pint jar exhausted on the plate of the air-pump, and the time observed which the gauge barometer required to fall through its range from 28 to 2 inches. During the

following experiments the height of the barometer was 29·3 inches, which is the value of 1 atmosphere, and the thermometer 53°.

Table VI.—Effusion of Air of different Densities.

Height of gauge barom. in inches.	Air of 1 atmosphere.		Air of 1·25 atmosphere.		Air of 1·5 atmosphere.		Air of 1·75 atmosphere.		Air of 2 atmospheres.		Air of 1 atmosphere.	
	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	III.	IV.
	″	″	″	″	″	″	″	″	″	″	″	″
28	0	0	0	0	0	0	0	0	0	0	0	0
20	116	116	90	91	76	75	65	65	56	55	117	117
12	118	118	92	91	76	76	64	64	56	56	118	118
8	65	65	47	48	38	38	33	33	30	29	66	67
4	79	80	50	50	41	40	33	32	26	28	80	80
2	54	54	26	25	18	18	16	17	14	13	54	53
	432	433	305	305	249	247	211	211	182	181	435	435

In these experiments the depression of the gauge barometer is not produced by a constant volume of the compressed air, but by a volume which is inversely proportional to the density of the compressed air; half a volume of air of 2 atmospheres being equal in the aspirator-jar, on the plate of the air-pump, to a whole volume of air of 1 atmosphere. Correcting the times of the preceding table, we have the passage of *equal volumes* of air of different densities, between the gauge height of 28 and 12 inches, as follows:—

		Time of effusion of equal volumes.	
Air of 1 atmosphere	. . . .	234·5 seconds	. . 1
Air of 1·25 atmosphere	. . . .	227·5 seconds	. . 0·9701
Air of 1·5 atmosphere	. . . .	227·2 seconds	. . 0·9688
Air of 1·75 atmosphere	. . . .	225·2 seconds	. . 0·9603
Air of 2 atmosphere	. . . .	223 seconds	. . 0·9510

It appears then that air of different densities between 1 and 2 atmospheres is effused in nearly equal times, the time of effusion diminishing slightly, not more than 5 per cent. with air of double tension. Taking the whole range of the preceding and present results, we have air varying in density from 0·25 to 2 atmospheres, or from 1 to 8, while the extreme variation in the time of the effusion of equal volumes is from 0·9510 to 1·1287, or from 1 to 1·1868.

In the lower part of the scale a more sensible inequality is perceived. Thus, with an exhaustion of from 8 to 4 inches in the aspirator-jar, the passage of equal volumes of air of different densities takes place in the following times:—

		Time of effusion of equal volumes.	
Air of 1 atmosphere	. . . .	145 seconds	. . 1
Air of 1·25 atmosphere	. . . .	121·9 seconds	. . 0·8407
Air of 1·5 atmosphere	. . . .	117·7 seconds	. . 0·8117
Air of 1·75 atmosphere	. . . .	114·6 seconds	. . 0·7903
Air of 2 atmospheres	. . . .	113 seconds	. . 0·7793

Here the time of effusion of air of 2 atmospheres falls about 22 per cent. below that of air of 1 atmosphere, while in the upper part of the scale the difference was only 5 per cent.

[8. *Effusion of Air of different Temperatures, by Plate* F.

This plate was a portion of thin platinum foil, with an aperture of an irregular hatchet form, of which the two greatest cross diameters were $\frac{1}{650}$th and $\frac{1}{520}$th of an inch. The perforated plate was attached to the end of the little brass cylinder by means of soft solder. A two-pint jar, giving a cavity of 72·54 cubic inches, was used as the aspirator-jar, and the time of the fall of the gauge barometer was observed from 28·5 to 23·5 inches, with the admission of dry air at different temperatures.

1. The temperature of the room being 41° FAHR., and the height of the barometer 29·616 inches, dry air entered the aspirator-jar in three experiments in 533, 532 and 530 seconds, of which the mean is 531·66 seconds. The room being afterwards heated up to 52°, the time of effusion of an equal volume of air was found to be, in three experiments, 525, 527 and 526 seconds, of which the mean is 526 seconds; or, a rise of 11° in temperature has shortened the time of effusion by 5·66 seconds. Taking the density of air at 32° as 1, at 41° it will be 0·9820, of which the square root is 0·9909; and at 52° it will be 0·9609, of which the square root is 0·9802. Now the relative times of effusion observed, namely, 531·66 and 526 seconds, are as 0·9909 to 0·9803, numbers which all but coincide with the square roots of the densities, 0·9909 and 0·9802, at the two different temperatures.

2. With the barometer at 30·186 to 30·150 inches, experiments were again made on the effusion of the same volume of dry air at 38°, 48° and 58°, four hours elapsing between each set of experiments, which were required to bring up the room and apparatus to a uniform and steady temperature. In three experiments at each temperature,—

The time of effusion at 38° was 526, 527 and 526 seconds: mean 526·33.
The time of effusion at 48° was 520, 521 and 520 seconds: mean 520·33.
The time of effusion at 58° was 515, 516 and 515 seconds: mean 515·33.

Here the first rise of 10° shortens the time of effusion 6 seconds, and the second rise of 10° shortens the time 5 seconds more. The density of dry air being 1 at 32°, it is at 38°, 0·9879; at 48°, 0·9684; and at 58°, 0·9497, of which three last densities the square roots are 0·9939, 0·9841 and 0·9745 respectively. Now the three mean times of effusion observed are in the proportion of the numbers 0·9939, 0·9826 and 0·9731, which correspond more closely with the preceding square roots than could be expected from the nature of the experiments. It appears then that *the effusion time of air of different temperatures is proportional to the square root of its density at each temperature.* The velocity of the effusion will be inversely as the square root of the air's density. Hence two volumes of air which have not the same tempera-

ture, are, in regard to effusion, like different gases possessing the densities of the air at the two temperatures.

As the velocity of the effusion of air does not increase at a rate so rapid as the direct proportion of its expansion by heat, it follows that the flow of air under pressure, through a small aperture, is retarded by heating the air; that is, the same absolute quantity or weight of air will take a longer time to pass, when rarefied by heat, than when in a dense state.

I have made several experiments on the influence of *aqueous vapour* upon the effusion of air. When dry air was effused into an aspirator-jar with the gauge barometer attached, and immediately afterwards air saturated with moisture at the same temperature, the latter passed through in sensibly the same time with comparatively large apertures, but in a shorter time with small apertures, although in general without much uniformity in successive experiments. Thus the time for dry air being constant at 524 seconds with plate F of small aperture, barometer 29·812, and thermometer 49°; with moist air, the time gradually fell, till at last it appeared to settle at 506 seconds, that number being obtained in three successive experiments; the temperature in the mean time having risen to 51°. There is here an acceleration of 18 seconds, of which not more than 2 seconds are accounted for by the diminished density of the moist air, and 1 second more by the rise in temperature. The moist air seemed also to have an extraordinary effect in opening and enlarging fissures, and very soon rendered more than one platinum plate useless, which was fixed by brazing, by that action. Nov. 1847.]

Part II.—TRANSPIRATION OF GASES.

1. *Transpiration of Air of different Densities or Elasticities, by a Glass Capillary Tube* E.

(*a.*) The same arrangements were adopted as in the effusion of air of different densities, lately described, the capillary tube being interposed in the place of the perforated plate. The apparatus employed is represented in fig. 4. Plate XXXIII.

With barometer 29·28, and thermometer 54°, 65 cubic inches of dry air of the atmospheric density were transpired from the globular vessel *a* (fig. 2), into a good vacuum sustained by continued pumping, through a capillary glass tube E, twenty feet in length; the same volume of air of 0·75 atmosphere and 0·5 atmosphere, measured at these pressures, were also transpired by the same capillary. The times were as follows :—

	I.	II.	Mean.
Transpiration of air of 1 atmosphere	799″	800″	799″·5
Transpiration of air of 0·75 atmosphere	1049	1051	1050
Transpiration of air of 0·5 atmosphere	1545	1542	1543·5

It is obvious that the times approach the inverse ratio of the tensions, as will appear more clearly on comparing the times observed with those calculated on that principle.

	Time observed.	Time calculated.
Transpiration of air of 1 atmosphere	1	1
Transpiration of air of 0·75 atmosphere	1·3133	1·3333
Transpiration of air of 0·5 atmosphere	1·9306	2

With air of higher tension than 1 atmosphere, the same apparatus for compression was also employed as in the effusion experiments (fig. 3). The capillary E communicated with the two-pint aspirator-jar (capacity 72·54 cubic inches), which was fully exhausted on the plate of the air-pump. The air being then allowed to pass into the capillary, the instant of time was noted when the gauge barometer fell to 28 inches, and the other points described below. The external barometer stood at 29·08 inches ; thermometer at 53°.

TABLE VII.—Transpiration of Air of different Densities.

Gauge barometer in inches.	Air of 1 atmosphere.		Air of 2 atmospheres.		Air of 1·75 atmosphere.		Air of 1·5 atmosphere.		Air of 1·25 atmosphere.		Air of 1 atmosphere.
	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	III.
28	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″
20	253	254	66	67	85	86	114	114	162	161	255
12	310	310	70	69	91	90	123	124	182	179	311
8	220	220	37	37	49	49	69	70	110	109	221
4	349	352	39	40	53	53	78	77	132	134	346
2	328	328	20	19	29	28	41	41	78	79	229
	1460	1464	232	232	305	306	425	426	664	662	1462

The times of transpiration in the preceding table require to be corrected, as they represent the passage of equal volumes of air measured after and not before the transpiration. Thus the same depression of the gauge barometer would be produced by half a volume of air of 2 atmospheres, as by a whole volume of air of 1 atmosphere; and it is necessary therefore to double the times observed of air of the former density, to obtain the time of passage of a whole volume. For the transpiration of equal volumes, in the gauge-range from 28 to 20 inches, which is most nearly equivalent to the action of a vacuum, we have—

Equal volumes.	Observed time of transpiration.		Calculated time.
Air of 1 atmosphere........	254 seconds........	1	1
Air of 1·25 atmosphere........	201·9 seconds........	0·7949	0·8000
Air of 1·5 atmosphere........	171 seconds........	0·6732	0·6666
Air of 1·75 atmosphere........	149·6 seconds........	0·5890	0·5714
Air of 2 atmospheres	133 seconds........	0·5236	0·5

The calculated times of the last column are the reciprocals of the tension, or number of atmospheres in the first column; they represent the observed times within a sufficient degree of approximation, to prove that *for equal volumes of air of different densities, the times of transpiration are inversely as the densities.* The velocity of transpiration will therefore be directly in proportion to the density of the air; air of double density being transpired into a vacuum in half time.

This at once separates the action of a capillary tube from that of a minute aperture; for air of all densities, it will be remembered, passes into a vacuum by effusion with equal velocity.

A consequence of this law immediately appears in conducting transpiration experiments, in the marked influence of the height of the barometer on the time of transpiration; the higher the barometer and the denser the air, the more quickly does a constant volume of it pass through a capillary tube into a vacuum.

This appears also to separate transpiration from the ordinary action of friction, for the denser the air, the more should its passage be retarded by friction.

[2. *Transpiration of Air of different Temperatures.*

Dry air was transpired by a glass capillary tube K, of fine bore, 39·4 inches in length, into a two-pint jar till the gauge barometer fell from 28·5 to 23·5 inches, in 796, 794 and 794 seconds, in three successive experiments, made at the temperature of 41° Fahr., and with the barometer at 30·052 inches. Four hours afterwards, the air and all the apparatus having been for some time at 58°, an equal volume of dry air was transpired twice in 814 seconds. A difference of 17 degrees of temperature has made a difference of 19 seconds in the time of transpiration, and *the dense cold air is transpired most rapidly.* The times are nearly in the inverse ratio of the square root of the densities of air at the two temperatures.

The transpiration of air in the first experiments which are made in the morning is often observed to be more rapid than in those which follow, owing I believe to the low nocturnal temperature being retained for some time by the glass capillary. January, 1847.]

3. *Preliminary Experiments on the Transpiration of different Gases by Capillary Tubes,* A, B *and* C.

The times of transpiration of the gases will be expressed in the sequel with reference to the time of oxygen as unity instead of that of air. Assuming what is now almost universally conceded, that the atomic weights of the following elements are exactly expressed by entire numbers, namely, oxygen by 8, nitrogen by 14, carbon by 6, and hydrogen by 1, and that while the equivalent proportion of the first affords one volume of gas, that of each of the others affords two volumes, we obtain the following theoretical densities for these elements and several of their gaseous compounds. The experimental determinations which appear to be of most value are subjoined.

TABLE of Specific Gravities of Gases.

	Air = 1.		Oxygen = 1 and 16.		
	Calculated.	Observed.	Calculated.		Observed.
Oxygen	1·1099*	1·10563 REGNAULT.	1	16	1
Nitrogen	0·9712	0·97137 REGNAULT.	0·8750	14	0·8785 REGNAULT.
Air	1	1	0·9010	14·416	0·9038 REGNAULT.
Hydrogen	0·06937	0·06926 REGNAULT.	0·0625	1	0·0626 REGNAULT.
Carbon	0·4162	......	0·3750	6	
Carbonic acid	1·5261	1·52901 REGNAULT.	1·3750	22	1·3830 REGNAULT.
Nitrous oxide	1·5261	......	1·3750	22	
Nitric oxide	1·0405	......	0·9375	15	
Carbonic oxide	0·9712	0·9678 WREDE.	0·8750	14	0·8754 WREDE.
Carburetted hydrogen	0·5549	0·555 THOMSON and HENRY.	0·5000	8	0·5001 THOMSON and HENRY.
Olefiant gas	0·9712	0·9852 SAUSSURE.	0·8750	14	0·8904 SAUSSURE.
Sulphuretted hydrogen	1·1793	1·1912 GAY-LUSSAC and THENARD	1·0625	17	1·0766 GAY-LUSSAC and THENARD.

With the exception of the recent valuable determinations of M. REGNAULT and Baron WREDE, the calculated specific gravities are probably nearer the truth and more to be depended on than the experimental results found in books, which are old, and generally not made with that degree of precision which the science now requires.

Capillary A.—This glass tube was thirty inches in length, and of a fine cylindrical bore; it allowed 1 cubic inch of air of the usual tension, to pass into a vacuum in about 13 seconds. A pint-jar was exhausted, of which the capacity, including the vacuous spaces of the air-pump, was 41·64 cubic inches. The gas entered into this space, passing through the capillary, and depressed the attached gauge barometer in the times stated in the following Tables :—

TABLE VIII.—Transpiration by Capillary A into a one-pint jar. Barom. 29·55. Temp. 61°.

Gauge barometer in inches.	Air.		Oxygen.		Hydrogen.	
	I.	I.	I.	II.	I.	II.
	"	"	"	"	"	"
28	0	0	0	0	0	0
20	150·5	150	166·5	166	71	70·5
12	181·5	182	201	201·5	87	87
4	321	321	354·5	354	156	155
2	......	......	213·5	215·5	94·5	94·5
From 28 to 4 inches	653	653				
From 28 to 2 inches	......	......	935·5	937	408·5	407

* Assigning the theoretical densities of 14 and 16 to nitrogen and oxygen, and assuming air to be composed of 79·2 volumes of the first, and 20·8 volumes of the second, the density of air will be expressed by the intermediate number 14·416; or, with the density of air $=1$, the density of oxygen becomes 1·1099, and the density of nitrogen 0·9711, both as given above. Hydrogen is calculated in the same column as $\frac{1}{16}$th of oxygen (1·1099), carbon as $\frac{6}{16}$ths, carbonic acid and nitrous oxide as each $\frac{22}{16}$ths; nitric oxide as the mean of nitrogen and oxygen, carbonic oxide and olefiant gas as $\frac{14}{16}$ths of oxygen; carburetted hydrogen as $\frac{8}{16}$ths, and sulphuretted hydrogen as $\frac{17}{16}$ths.

Mean Results.

Gauge barometer.		Air.	Hydrogen.
From 28 to 20 inches	Time in seconds	150·25	70·75
	Time of oxygen=1...	0·9037	0·4255
From 20 to 12 inches	Time in seconds	181·75	87
	Time of oxygen=1...	0·9031	0·4322
From 12 to 4 inches	Time in seconds	321	155·5
	Time of oxygen=1...	0·9061	0·4389
From 4 to 2 inches	Time in seconds	....	94·5
	Time of oxygen=1...	....	0·4405
From 28 to 4 inches	Time in seconds	653	313·25
	Time of oxygen=1...	0·9047	0·4340
From 28 to 2 inches	Time in seconds	....	407·75
	Time of oxygen=1...	....	0·4355

Table IX.—Transpiration by Capillary A into a one-pint jar. Barom. 29·5. Temp. 58°·5.

Gauge barometer in inches.	Air.		Oxygen.		Carburetted hydrogen.		Carbonic acid.	
	I.	II.	I.	II.	I.	II.	I.	II.
28	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0
20	150	150	166·5	166	94·5	94·5	131	131
12	182·5	182	202	201·5	118·5	119	158	158
4	318·5	318	359·5	357	198·5	198	272	271
2	190·5	192	217	216	119	118	159	159
From 28 to 2 inches	841·5	842	945·5	940·5	530·5	529·5	720	719

Mean Results.

Gauge barometer.		Air.	Carburetted hydrogen.	Carbonic acid.
From 28 to 20 inches	Time in seconds	150	94·5	131
	Time of oxygen=1...	0·9022	0·5684	0·7879
From 20 to 12 inches	Time in seconds	182·25	118·75	158
	Time of oxygen=1...	0·9033	0·5886	0·7831
From 12 to 4 inches	Time in seconds	318·25	198·25	271·5
	Time of oxygen=1...	0·8914	0·5505	0·7600
From 4 to 2 inches	Time in seconds	191·25	118·5	159
	Time of oxygen=1...	0·8833	0·5473	0·7344
From 28 to 2 inches	Time in seconds	841·75	530·	719·5
	Time of oxygen=1...	0·8928	0·5622	0·7633

It will be observed that the proportion between the times of oxygen and air is subject to a variation at different parts of the scale, but is so small as to be within the errors of observation ; while this nearly constant ratio of their times coincides almost with that of their specific gravities (1 to 0·9038 Regnault).

The time or rate of hydrogen varies to the extent of 0·015 at different parts of the scale, the passage of that gas being relatively quicker at high than at low pressures.

It is a question how far this variation in the ratio is owing to the action of effusion; the time of effusion of this gas being only 0·25, referred to oxygen as unity, while its time of transpiration is 0·4355. The influence of effusion upon the rate of passage is likely to be most considerable when the pressure is greatest; and that of transpiration, on the contrary, most considerable when the resistance to the passage of the gas is greatest and the pressure least, that is, in the lower part of the scale.

It may be observed that the transpiration time of hydrogen does not differ far from 0·4375, which is one-half of the transpiration time of nitrogen, calculated from the experiment on air, or seven-sixteenths of that of oxygen.

Carbonic acid appears to be much more quickly transpired than oxygen, although denser than that gas in the ratio of 11 to 8; but the effusion time of carbonic acid being slow, any influence of effusion will increase the time of transpiration of this gas,—the reverse of what occurs with hydrogen. The transpiration time of carbonic acid varies considerably at different pressures, being slower by 0·0535 at the upper than the lower part of the scale. An approach to 0·75, or twelve-sixteenths of the time of oxygen, may be noted at present in the rate of this gas.

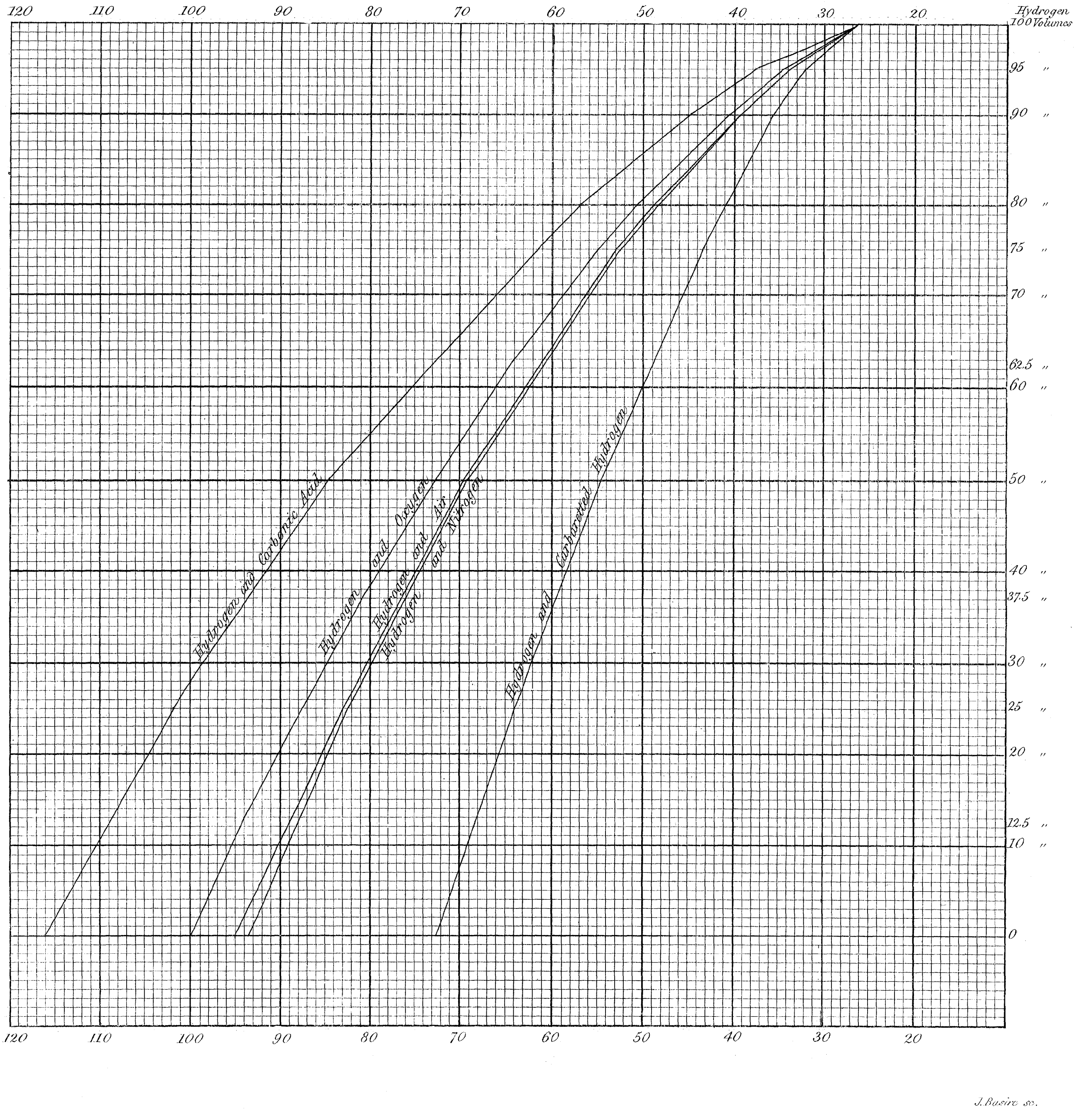
The transpiration rate of carburetted hydrogen appears to be affected by an error of observation in the middle part of the scale; but its rate is slower at the upper part than at the lower, to the extent of 0·0211. This is also in accordance with the assumed influence of effusion, the effusion time of this gas being greater than its transpiration time. The transpiration time of carburetted hydrogen is not in direct proportion to its gravity, which is 0·5, or one-half of that of oxygen: it approaches more nearly to 0·5625, which is nine-sixteenths of the time of oxygen.

Capillary B.—This glass tube was 31·5 inches in length, of a round bore, but decidedly conical. It was first placed so that the gas entered the tube by the large and escaped by the small opening. When so arranged this tube allowed 1 cubic inch of air to pass into a vacuum in 34·3 seconds, or the transpiration was nearly three times slower than by A.

Table X.—Transpiration by Capillary B into a half-pint jar (21·26 cubic inches). Barom. 29·17. Temp. 68°.

Gauge barometer in inches.	Oxygen.		Nitrogen.			Carburetted hydrogen.	
	I.	II.	I.	II.	III.	I.	II.
	″	″	″	″	″	″	″
28	0	0	0	0	0	0	0
20	235·5	235·5	209	205	205	133	133
12	289	290·5	252	253	......	162·5	163
4	521	521	451·5	453·5	......	290·5	290·5
2	290·5	290	258	255·5	......	164	165·5
From 28 to 2 inches ...	1336	1337	1170·5	1167	205	750	752

Effusion of mixed Gases.



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Mean Results.

Gauge barometer.		Nitrogen.	Carburetted hydrogen.
From 28 to 20 inches	Time in seconds	206·3	133
	Time of oxygen=1...	0·8760	0·5647
From 20 to 12 inches	Time in seconds	252·5	162·7
	Time of oxygen=1...	0·8716	0·5618
From 12 to 4 inches	Time in seconds	452·5	290·5
	Time of oxygen=1...	0·8685	0·5576
From 4 to 2 inches...	Time in seconds	256·7	164·7
	Time of oxygen=1...	0·8845	0·5677
From 28 to 2 inches	Time in seconds	1168·7	751
	Time of oxygen=1...	0·8740	0·5619

Table XI.—Transpiration by Capillary B into a half-pint jar. Barom. 29·2.

Gauge barometer in inches.	Oxygen.			Hydrogen.			Carbonic acid.		
	I.	II.	III.	I.	II.	III.	I.	II.	III.
	62°	62°·5	64°·5	65°	65°	65°·5	66°	66°	66°
28	0″	0″	0″	0″	0″	0″	0″	0″	0″
20	234	234	234·5	103	103	103	174·5	174	173
12	285	287·5	288·5	126·5	126	126·5	212	211·5	212
4	516	516	516·5	229·5	228	228	376	379·5	376
2	290	292·5	288·5	129	126	132	....	213	212·5
	62°·5	64°	64°·5	65°	65°·5	....	....	66°	66°
From 28 to 2 inches ...	1325	1330	1328	588	583	589·5	....	978	974

Mean Results.

Gauge barometer.		Hydrogen.	Carbonic acid.
From 28 to 20 inches	Time in seconds	103	173·8
	Time of oxygen=1......	0·4398	0·7424
From 20 to 12 inches	Time in seconds	126·3	211·8
	Time of oxygen=1......	0·4403	0·7385
From 12 to 4 inches	Time in seconds	228·5	377·3
	Time of oxygen=1......	0·4425	0·7310
From 4 to 2 inches...	Time in seconds	129	212·75
	Time of oxygen=1......	0·4443	0·7327
From 28 to 2 inches	Time in seconds	586·8	976
	Time of oxygen=1......	0·4413	0·7351

Taking the higher part of the scale, from 28 to 20 inches, which approaches nearest to transpiration into a vacuum, we obtain the following times of transpiration:—Oxygen 1, nitrogen 0·8760, hydrogen 0·4398, carburetted hydrogen 0·5647, carbonic acid 0·7424; which almost coincide with the numbers lately mentioned in relation to these gases, with the exception of carbonic acid, which is 0·7424 instead of 0·75. With the great resistance of this tube, the variation in ratio at different parts of the scale has also become very small, being only 0·0045 for hydrogen and 0·0097 for carbonic acid. The disturbing influence of effusion appears therefore to be in a great measure eliminated. It is also worthy of remark, that the time of passage of

carbonic acid into a perfect vacuum would certainly approach still more nearly to 0·75; for the rate of transpiration of that gas appears, in the case of the present capillary, to become slower with the increase of pressure. It will be seen hereafter that the gases deviate very sensibly at low pressures from the empirical coefficients of transpiration which have been named, becoming slower in their passage with reference to oxygen, as is here observed of carbonic acid. This deviation appears to be connected with excessive resistance, whether arising from the smallness of the capillary opening or diminished pressure.

With the view of observing the effect of alterations in the position and dimensions of a capillary, experiments were now made with this tube, (1) in an inverted position, so that the gas entered by the narrow and escaped by the wide end, and (2) after being reduced to half its original length.

Capillary B *reversed.*—The passage of gas through this tube was nearly three times more rapid in the new direction, 1 cubic inch of air being now transpired into a vacuum in 12·6 seconds. The length of the tube and resistance to passage through it are therefore nearly the same as in capillary A; but while the latter was of uniform bore, the present capillary is highly conical.

TABLE XII.—Transpiration by Capillary B reversed into a one-pint jar. Barom. 30·13.

Gauge barometer in inches.	Air.			Oxygen.			Hydrogen.		Carbonic acid.		
	I.	II.	III.	I.	II.	III.	I.	II.	I.	II.	III.
	59° F.	59° F.	59° F.	61° F.			61°·5F.	61°·5F.	62° F.	62° F.	
28	0''	0''	0''	0''	0''	0''	0''	0''	0''	0''	0''
20	149·5	144·5	145	160	160	160	69	69	127	126	126
12	173·5	177·5	178	198	196	196	86	85·5	154	153	152
4	318	318	317	352·5	353·5	353·5	157·5	157·5	268·5	267·5	268·5
2	190	189·5	192·5	216	216·5	215	96	96·5	154·5	155	156·5
From 28 to 12 inches...	323	322	323	358	356	356	155	154·5	281	279	278
From 28 to 2 inches...	831	829·5	832·5	926·5	926	924·5	408·5	408·5	704	701·5	703

Mean Results.

Gauge barometer.		Air.	Hydrogen.	Carbonic acid.
From 28 to 12 inches	Time in seconds	322	154·75	279·33
	Time of oxygen=1...	0·9024	0·4338	0·7831
From 12 to 4 inches	Time in seconds	317·7	157·5	268·16
	Time of oxygen=1...	0·8994	0·4459	0·7595
From 4 to 2 inches	Time in seconds	190·7	96·25	155·33
	Time of oxygen=1...	0·8836	0·4459	0·7197
From 28 to 2 inches	Time in seconds	831	408·5	702·83
	Time of oxygen=1...	0·8978	0·4413	0·7594

The coefficients of air and hydrogen, although still corresponding very closely with the numbers 0·9038 and 0·4375, begin to exhibit a sensible variation in different parts of the scale. The variation in carbonic acid is considerable, amounting to 0·0634, and the divergence is on both sides of the empirical number 0·75.

Capillary B *shortened.*—The tube was preserved in its last position, but its length reduced to 14·5 inches. It now allowed 1 cubic inch of air to pass into a vacuum in 6·4 seconds; or twice as rapidly as when entire.

Table XIII.—Transpiration by Capillary B ($14\frac{1}{2}$ inches long) into a one-pint jar. Barom. 30·12.

Gauge barometer in inches.	Air.			Oxygen.			Nitrogen.		Carburetted hydrogen.			Hydrogen.			Carbonic acid.	
	I.	II.	III.	I.	II.	III.	I.	II.	I.	II.	III.	I.	II.	III.	I.	II.
				62° F.	62° F.	62° F.	63° F.	63° F.	62° F.	61° F.	62° F.	62° F.	62° F.	62° F.	62° F.	62° F.
28	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″
20	75	75	75·5	82·5	83·5	82	72	72	48	48	48	34·5	34	34	69	69
12	89·5	89·5	89·5	99·5	99·5	100	87·5	88	57	57	57	41·5	41·5	41·5	81	80·5
4	158	157	157·5	175	175·5	174·5	152·5	152·5	98	98	98	75	75	75	137·5	136·5
2	91·5	91	92	102	103	102·5	91	89·5	56	56	55·5	45·5	45·5	45	77	77·5
From 28 to 12 in.	164·5	164·5	164·5	182	183	182	159·5	160	105	105	105	76	75·5	75·5	150	149·5
From 28 to 2 in.	414	412·5	414·5	459	461·5	459	403	402	259	259	258·5	196·5	196	195·5	364	363·5

Mean Results.

Gauge barometer.		Air.	Nitrogen.	Carburetted hydrogen.	Hydrogen.	Carbonic acid.
From 28 to 12 inches	Time in seconds	164·5	159·75	105	75·66	149·7
	Time of oxygen=1...	0·9023	0·8763	0·5728	0·4150	0·8211
From 12 to 4 inches	Time in seconds	157·5	152·5	98	75	137
	Time of oxygen=1...	0·9000	0·8714	0·5600	0·4285	0·7828
From 4 to 2 inches	Time in seconds	91·5	90·25	55·83	45·33	77·25
	Time of oxygen=1...	0·8926	0·8804	0·5447	0·4325	0·7546
From 28 to 2 inches	Time in seconds	413·7	402·5	258·83	196	363·75
	Time of oxygen=1...	0·8999	0·8755	0·5632	0·4263	0·7912

The times are now too short for accurate numerical determinations, but it is obvious that while the relative times of air and nitrogen are little changed, particularly from 28 to 4 inches, the times of hydrogen and carbonic acid are sensibly affected by effusion, and most so in the upper part of the scale; the coefficient of hydrogen falling to 0·4150, while that of carbonic acid rises to 0·8211. From 4 to 2 inches, the rates are 0·4325 and 0·7546; numbers which still diverge a little from the empirical coefficients, but both in the direction of the effusion influence.

Reduced to 7 inches in length and now allowing 1 cubic inch of air to pass into a vacuum in 3·4 seconds, this capillary was found to be still less adapted for transpiration. In a series of observations, which are not of sufficient importance to be particularly detailed, the coefficients of the gases in the range from 28 to 12 inches, were,—air 0·9194, nitrogen 0·8983, carburetted hydrogen 0·6029, carbonic acid 0·9028, and hydrogen 0·3930: numbers which demonstrate an increasing interference of effusion. In the range from 12 to 4 inches, the coefficients were,—air 0·9114, nitrogen 0·8851, carburetted hydrogen 0·5764, carbonic acid 0·8303, hydrogen 0·4180.

Of this last portion of capillary B, 5·5 inches were found to contain 2·78 grains of mercury; which gives the tube a mean diameter of 0·0137, or $\frac{1}{73}$rd of an inch.

Capillary C.—This was a tube of exceedingly fine bore; 8·3 inches of the tube

containing only 0·65 grain of mercury; which gives a diameter of 0·00539 inch, or about $\frac{1}{186}$th of an inch. Experiments were made with portions of this tube of different lengths; and first with a portion only 1 inch in length, in which it was expected that the influence of effusion would be considerable, from its approach to an aperture in a thin plate.

TABLE XIV.—Transpiration by Capillary C (1 inch long) into a one-pint jar. Barom. 28·81. Temp. 60°.

Gauge barometer in inches.	Air.		Oxygen.		Hydrogen.		Carbonic acid.
	I.	II.	I.	II.	I.	II.	I.
28	0″	0″	0″	0″	0″	0″	0″
20	248·5	249	273	271·5	108	108	237·5
12	283	281·5	308·5	308·5	126	127	261
8	186·5	185·5	204·5	206	87	87	167
4	284	286	315·5	314	136	137	244
2	270·5	266·5	301	302	133	132	227
From 28 to 2 inches	1272·5	1268·5	1402·5	1402	590	591	1136·5

Mean Results.

Gauge barometer.		Air.	Hydrogen.	Carbonic acid.
From 28 to 20 inches	Time in seconds	248·75	108	237·5
	Time of oxygen=1...	0·9138	0·3967	0·8725
From 28 to 12 inches	Time in seconds	531	234·75	498·5
	Time of oxygen=1...	0·9139	0·4040	0·8594
From 20 to 12 inches	Time in seconds	282·25	126·5	261
	Time of oxygen=1...	0·9149	0·4100	0·8460
From 12 to 8 inches	Time in seconds	186	87	167
	Time of oxygen=1...	0·9063	0·4238	0·8138
From 8 to 4 inches	Time in seconds	285	136·5	244
	Time of oxygen=1...	0·9054	0·4339	0·7751
From 4 to 2 inches	Time in seconds	268·5	132·5	227
	Time of oxygen=1...	0·8905	0·4374	0·7529
From 28 to 2 inches	Time in seconds	1270·5	590·5	1136·5
	Time of oxygen=1...	0·9060	0·4211	0·8104

TABLE XV.—Transpiration by Capillary C (2 inches long) into a half-pint jar. Barom. 29·32.

Gauge barometer in inches.	Air.		Oxygen.		Hydrogen.	
	I.	II.	I.	II.	I.	II.
28	0″	0″	0″	0″	0″	0″
20	211·5	211·5	234	234	101·5	102
12	254	254	281·5	281	124·5	124
8	176·5	176·5	196	197	88	88
4	280·5	280·5	321·5	320	141·5	138
2	273	272	301	302	141	146
From 28 to 2 inches	1195·5	1196	1334	1334	596·5	598

Mean Results.

Gauge barometer.		Air.	Hydrogen.
From 28 to 20 inches	Time in seconds	211·5	101·75
	Time of oxygen=1...	0·9038	0·4348
From 20 to 12 inches	Time in seconds	254	124·25
	Time of oxygen=1...	0·9031	0·4417
From 12 to 8 inches	Time in seconds	176·5	88
	Time of oxygen=1...	0·8981	0·4478
From 8 to 4 inches	Time in seconds	281·25	139·75
	Time of oxygen=1...	0·8768	0·4357
From 4 to 2 inches	Time in seconds	272·5	143·52
	Time of oxygen=1...	0·9038	0·4759
From 28 to 2 inches	Time in seconds	1195·75	597·25
	Time of oxygen=1...	0·8964	0·4476

Table XVI.—Transpiration by Capillary C (4 inches long) into a half-pint jar.

Gauge barometer in inches.	Air. I.		Air. II.		Oxygen. I.	
	65°		65°		65°	
28	″		0″		0″	
24	205	419	205	419	228	467
20	214		212		239	
16	234	510	236	510	262	575
12	276		278		313	
10	166	361	163	360	183	403
8	195		197		220	
6	248		245		273	
5	145	570	151	580	169	648
4	177		184		206	
3	241	573	238	568	265	659
2	332		330		394	
From 28 to 2 inches	2433		2439		2752	

Mean Results.

Gauge barometer.		Air.
From 28 to 24 inches	Time in seconds	205
	Time of oxygen=1...	0·8991
From 28 to 20 inches	Time in seconds	418
	Time of oxygen=1...	0·8951
From 20 to 12 inches	Time in seconds	512
	Time of oxygen=1...	0·8904
From 12 to 8 inches	Time in seconds	360·5
	Time of oxygen=1...	0·8945
From 8 to 4 inches	Time in seconds	575
	Time of oxygen=1...	0·8657
From 4 to 2 inches	Time in seconds	570·5
	Time of oxygen=1...	0·8657
From 28 to 2 inches	Time in seconds	2436
	Time of oxygen=1...	0·8852

The velocity with which air passed into a vacuum was, by C 1 inch, 1 cubic inch in 21·26 seconds; by C 2 inches, 1 cubic inch in 35·43 seconds; and by C 4 inches, 1 cubic inch in 70 seconds.

C 1 inch exhibits (Table XIV.) great variation in its rate of transpiration at different pressures, as was to be expected. At the head of the scale, the rate of air is 0·9138, of hydrogen 0·3967, and of carbonic acid 0·8725; which all indicate a great interference of effusion. At the bottom of the scale, on the other hand, where the pressure is small and the resistance to passage consequently great, the rate of air is 0·8905, of hydrogen 0·4374, and of carbonic acid 0·7529, or nearly normal.

With C 2 inches (Table XV.), the rates of air are pretty uniform at different parts of the scale, and sufficiently normal; the deviation from 8 to 4 inches appears to be an accidental anomaly. The rate of hydrogen also is never distant from 0·4375, except at the very bottom of the scale. This appears to be the length of a tube of so small a bore which gives the most uniform results at different pressures:

For with C 4 inches (Table XVI.), where the resistance is excessive, air has a rate corresponding sufficiently with its specific gravity at the head of the scale, but diverging rapidly in the lower part of the scale, the time of transpiration becoming rapid as compared to that of oxygen. With a tube then like the present, the relation between the times of transpiration is only to be looked for within a limited range, and that at a high degree of pressure approaching to a whole atmosphere.

4. *Transpiration by Capillary Tube* H.

As the existence of any simple numerical relation among the gases, such as the preceding experiments on transpiration render probable, would be a point of fundamental importance in their history, I was induced to try new capillary tubes and to multiply experiments, varying the circumstances in which they were made, and taking additional precautions against the interference of disturbing causes. The arbitrary nature of the coefficients of transpiration indeed produces a more than usual necessity for strong evidence and numerous confirmations, as the numbers themselves have no *a priori* probability in their favour.

It appeared desirable to try capillary tubes of larger diameter than those already employed, and of great length; partly to vary the conditions of the experiment, and partly because extreme shortness of tube appears, in the experiments made with C, to be unfavourable to uniformity of rate at different pressures.

Several portions of capillary tube, of which the bore was as nearly equal as could be judged of by the eye, were accordingly selected and cemented together at the blowpipe, so as to form a continuous tube 22 feet in length, which was bent up into coils for convenience in using it, as represented in figure 4, Plate XXXIII. The extremities of this capillary were connected with the block-tin tubes proceeding from the drying tube and air-pump jar respectively, by means of thick caoutchouc adopters, which diminished the rigidity of the arrangement and protected the glass tube from the effect of the shocks, which are unavoidable in working the air-

pump. This capillary (H) allowed 1 cubic inch of air to pass into a vacuum in 15·64 seconds. Two inches of the tube were found to hold 2·65 grains of mercury, which gives a diameter of 0·0222 inch, or $\frac{1}{45}$th of an inch. The tube, however, may have been more contracted at the bendings.

Air-pump jars of greater size were also employed, so as to protract the time of passage, and give larger numbers. Of these vessels, which I have termed aspirator jars, the capacity of the "three-pint jar" was 103·56 cubic inches, and that of the "six-pint jar" 201·78 cubic inches; the vacuous channels of the air-pump and connecting tubes being included in these measurements.

The temperatures recorded are those of the interior of the aspirator jar, observed by a very small mercurial thermometer, containing no more than 50 or 60 grains of mercury, and therefore highly sensitive. It will be remarked that the temperature within the receiver always rises, and in general about half of a degree Fahrenheit during the continuance of an experiment: this is owing to the compression of the gas already in the receiver by that which enters. The change of temperature due to this cause becomes less considerable with large aspirator jars, which are preferable to small jars for this and other reasons.

As it appears that the relation between the coefficients of transpiration is only to be looked for at high pressures, attention should be more directed to the rates of transpiration in the upper than in the lower part of the scale. The inquiry will therefore be directed with the view of solving the question, What are the coefficients of transpiration of the different gases into a vacuum, or under considerable pressures?

Table XVII.—Transpiration by Capillary H. into a three-pint jar. Barom. 30·324.

Gauge barometer in inches.	Air.		Oxygen.		Hydrogen.		Hyd. 95+5 air.		Carbonic acid.	
	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.
	61°·5	61°·5	61°·5	61°·5	61°·5	61°·5	61°·5	61°·5	61°·5	61°·5
28	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″
24	213	213	236	237	104	104	125	124	178	177
20	227	227	254	253	111	111	132	132	188	188
12	549	549	611	611	268	269	321	321	454	455
8	389	388	435	435	192	192	227	227	321	320
	61°·75	61°·75	61°·75	61°·75	61°·75	61°·75	61°·75	61°·75	61°·75	61°·75
From 28 to 8 inches......	1378	1377	1536	1536	675	676	805	804	1141	1140

Mean Results.

Gauge barometer.		Air.	Hydrogen.	95 Hyd.+5 air.	Carbonic acid.
From 28 to 24 inches	Time in seconds	213	104	124·5	177·5
	Time of oxygen=1...	0·9006	0·4397	0·5264	0·7505
From 24 to 20 inches	Time in seconds	227	111	132	188
	Time of oxygen=1...	0·8954	0·4378	0·5206	0·7416
From 20 to 12 inches	Time in seconds	549	268·5	321	454·5
	Time of oxygen=1...	0·8985	0·4394	0·5252	0·7438
From 12 to 8 inches	Time in seconds	388·5	192	227	320·5
	Time of oxygen=1...	0·8931	0·4413	0·5218	0·7368
From 28 to 8 inches	Time in seconds	1377·5	675·5	864·5	1140·5
	Time of oxygen=1...	0·8968	0·4397	0·5237	0·7425

The numbers for air, hydrogen and carbonic acid accord well with those obtained by the other capillaries. The small addition of 5 per cent. of air to hydrogen has a surprising effect in retarding the transpiration of that gas. The mean rate of such a mixture, calculated from the rates of air and hydrogen separately, is 0·4625, whereas the actual rate is 0·5264. The rate of the mixture should only be increased by 0·0228, whereas it is really increased by 0·0840. Hence the effect of 5 per cent. of air in retarding the rate of hydrogen is nearly four times greater than it should be by calculation. The experiment shows the effect which a small amount of impurity must have in deranging the transpiration rate of that gas. I shall return again to this point under the subject of the transpiration of mixed gases.

TABLE XVIII.—Transpiration by Capillary H into a three-pint jar.
Barom. 30·3—30·242.

Gauge barometer in inches.	Oxygen.		Nitrogen.		Carbonic oxide.		Air.	
	I.	II.	I.	II.	I.	II.	I.	II.
	61°·5	61°·5	61°·5	61°·5	61°·5	61°·5	61°·5	61°·5
28	0″	0″	0″	0″	0″	0″	0″	0″
24	238	239	208	208	207	207	214	214
20	253	253	220	221	220	220	229	229
12	614	614	536	533	532	533	552	550
8	434	434	378	376	376	377	389	392
	61°·75	61°·75	62°	62°	62°	62°	62°	62°
From 28 to 8 inches	1539	1540	1342	1339	1335	1337	1384	1385

Mean Results.

Gauge barometer.		Nitrogen.	Carbonic oxide.	Air.
From 28 to 24 inches	Time in seconds	208	207	214
	Time of oxygen=1...	0·8721	0·8679	0·8972
From 24 to 20 inches	Time in seconds	220·5	220	229
	Time of oxygen=1...	0·8715	0·8695	0·9051
From 20 to 12 inches	Time in seconds	534·5	532·5	551
	Time of oxygen=1...	0·8705	0·8673	0·8974
From 12 to 8 inches	Time in seconds	377·5	376·5	390·5
	Time of oxygen=1...	0·8698	0·8675	0·8998
From 28 to 8 inches	Time in seconds	1340·5	1336	1384·5
	Time of oxygen=1...	0·8707	0·8678	0·8993

In the preceding table, a comparison is made between two gases, nitrogen and carbonic oxide, of which the theoretical specific gravities are the same, namely 0·8750, while the mean rate of nitrogen, from 28 to 12 inches, proves to be 0·8707, and that of carbonic oxide 0·8678, which is a pretty close approximation. In several other experiments with these gases, a slight difference in their coefficients of transpiration was observed, carbonic oxide having always the smaller number: the difference generally approached 0·0040. It is not at all impossible, however, that these gases

may really differ quite as much in specific gravity; the specific gravity of carbonic oxide found by WREDE being 0·8754, on the oxygen scale, while that of nitrogen by REGNAULT is 0·8785.

TABLE XIX.—Transpiration by Capillary H into a three-pint jar. Barom. 30·232.

Gauge barometer in inches.	Air.		Oxygen.		Carburetted hydrogen.	
	I.	II.	I.	II.	I.	II.
	65°·25	65°·25	66°	66°	66°	66°
28	0″	0″	0″	0″	0″	0″
24	215	216	239	240	131	131
20	229	230	255	256	141	141
12	555	553	617	616	338	338
8	393	393	439	437	240	240
	66°	66°	66°	66°	66°·25	66°·25
From 28 to 8 inches......	1392	1392	1550	1549	850	850

Mean Results.

Gauge barometer.		Air.	Carburetted hydrogen.
From 28 to 24 inches	Time in seconds	215·5	131
	Time of oxygen=1...	0·8997	0·5474
From 24 to 20 inches	Time in seconds	229·5	141
	Time of oxygen=1...	0·8982	0·5518
From 20 to 12 inches	Time in seconds	554	338
	Time of oxygen=1...	0·8986	0·5482
From 12 to 8 inches	Time in seconds	393	240
	Time of oxygen=1...	0·8972	0·5479
From 28 to 8 inches	Time in seconds	1392	850
	Time of oxygen=1...	0·8983	0·5485

TABLE XX.—Transpiration by Capillary H into a six-pint jar. Barom. 30·196—30·174.

Gauge barometer in inches.	Oxygen.		Carburetted hydrogen.		Hydrogen.		Air.	
	I.	II.	I.	II.	I.	II.	I.	II.
	66°·75	66°·75	66°·75	66°·75	66°·75	66°·75	67°	67°
28·5	0″	0″	0″	0″	0″	0″	0″	0″
26·5	228	232	126	128	102	101	207	204
24·5	235	233	130	128	102	104	212	211
23·5	121	121	66	67	54	54	108	110
	67°	67°	67°	67°	67°	67°	67°	67°
From 28·5 to 23·5 inches...	584	586	322	323	258	259	527	525

Mean Results.

Gauge barometer.		Carburetted hydrogen.	Hydrogen.	Air.
From 28·5 to 23·5 inches	Time in seconds	322·5	258·5	526
	Time of oxygen=1...	0·5512	0·4418	0·8991

Tables XIX. and XX. exhibit the transpiration rates of carburetted hydrogen and hydrogen, the former of which approaches to 0·55, which is certainly a sensible deviation from 0·5625. The number for hydrogen (0·4418), on the other hand, is but very little removed from 0·4375.

Table XXI.—Transpiration by Capillary H into a six-pint jar. Barom. 30·158—30·138.

Gauge barometer in inches.	Oxygen.		Carbonic oxide.			Nitrogen.		Nitrous oxide.		Carbonic acid.	
	I.	II.	I.	II.	III.	I.	II.	I.	II.	I.	II.
	67°	67°	67°	67°	67°	67°·75	67°·75	68°	68°	68°	68°
28·5	0′	0″	0′	0′	0	0	0′	0′	0′	0′	0″
26·5	230	231	202	200	201	202	202	173	173	173	173
24·5	237	235	202	203	204	205	205	176	175	174	176
23·5	121	121	107	107	106	108	108	91	91	92	92
	67°	67°	67°·25	67°·25	67°·25	68°	68°	68°	68°	68°	68°
From 28·5 to 23·5 inches	588	587	511	510	511	515	515	440	439	439	441

Mean Results.

Gauge barometer.		Carbonic oxide.	Nitrogen.	Nitrous oxide.	Carbonic acid.
From 28·5 to 23·5 inches	Time in seconds	510·5	515·	439·5	440
	Time of oxygen=1...	0·8689	0·8766	0·7480	0·7455

In the preceding table carbonic oxide and nitrogen are again compared, and also another remarkable pair of gases having the same theoretical density, namely carbonic acid and nitrous oxide. The two latter exhibit an extraordinary parallelism in their rates of transpiration in all experiments which were made upon them, provided due attention was paid to the purity of the nitrous oxide. The solution of nitrate of ammonia should always be *filtered*, and the salt crystallized, as the presence of a very minute quantity of solid matter may cause a change in the mode of decomposition of the salt by heat, and the evolution of a very sensible quantity of free nitrogen.

The carbonic oxide of experiments 1 and 2 was obtained by the action of oil of vitriol on pure oxalic acid; that of experiment 3 was prepared by the process of Mr. Fownes, namely heating oil of vitriol upon the ferrocyanide of potassium, avoiding a violent reaction by a proper regulation of the temperature. The gas of both processes was washed with alkali, although this precaution is scarcely required with the gas of the last process. The transpiration results are exactly the same with the gas prepared in both ways.

TABLE XXII.—Transpiration by Capillary H (with cupped ends) into a six-pint jar. Barom. 29·39. Temp. 51°.

Gauge barometer in inches.	Nitrogen.		Oxygen.		Olefiant gas.		Air.		Carburetted hydrogen.			
	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	III.	IV.
28·5	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″
26·5	203	204	233	235	122	121	211	211	129	129	129	129
24·5	206	207	236	236	122	122	212	212	129	131	130	130
23·5	104	104	121	120	62	63	108	108	67	66	66	66
From 28·5 to 23·5 inches	513	515	590	591	306	306	531	531	325	326	325	325

Mean Results.

Gauge barometer.		Nitrogen.	Olefiant gas.	Air.	Carburetted hydrogen.
From 28·5 to 23·5 inches.	Time in seconds ...	514	306	531	325·25
	Time of oxygen=1	0·8704	0·5182	0·9000	0·5512

For the experiments of the preceding table the form of the capillary H was so far altered, that a funnel-form was given to the apertures of the tube. This was done by softening the tube in the blowpipe flame, within an inch of each extremity, and expanding the bore into a small ball of about one tenth of an inch in diameter; the ball was afterwards cut across the middle, and left the tube of course with a cup-shaped termination. This change in the condition of the capillary seems to have no effect on the comparative rates of transpiration of the different gases.

It was found that the passage of air became a little slower by cupping the end of the tube by which the gas obtains ingress, in the proportion of 509 to 496; but cupping the point of egress occasioned no further change in the rate, the experiments being made within the pressures of 28·5 and 23·5 inches.

The transpiration rate of olefiant gas differs entirely from that of nitrogen and carbonic oxide, of which gases it possesses the theoretical specific gravity, and is a great deal more rapid; the transpiration coefficient being so low as 0·5182. The specific gravity of the gas made use of was found to be 0·9840, and it was absorbed by the perchloride of antimony to the extent of 96·5 per cent. The determination of the true coefficient for this gas is attended with unusual difficulty, from its constant and I believe unavoidable impurity, as prepared by the action of sulphuric acid upon alcohol.

TABLE XXIII.—Transpiration by Capillary H (with cupped ends) into a six-pint jar. Barom. 29·91. Temp. 54°.

Gauge barometer in inches.	Air.		Oxygen.		Hydrogen.		Carburet. hyd.		Carbonic oxide.		Carbonic acid.	
	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.
	″	″	″	″	″	″	″	″	″	″	″	″
28·5	0	0	0	0	0	0	0	0	0	0	0	0
26·5	212	212	234	233	105	105	133	133	206	204	175	176
24·5	212	212	235	236	105	106	134	132	204	205	176	174
23·5	108	107	121	119	53	53	66	67	106	106	90	90
From 28·5 to 23·5 inches	532	531	590	588	263	264	333	332	516	515	441	440

Mean Results.

Gauge barometer.		Air.	Hydrogen.	Carburetted hydrogen.	Carbonic oxide.	Carbonic acid.
From 28·5 to 23·5 inches	Time in seconds ...	531·5	263·5	332·5	515·5	440·5
	Time of oxygen=1	0·9024	0·4473	0·5645	0·8752	0·7479

The results of the preceding table are remarkable as approaching more closely to the empirical numbers than any preceding results obtained by the same capillary. The same observation applies to the results of the table which immediately follows. In the one table, the number for carbonic oxide is 0·8732, in the other 0·8752; the numbers for carbonic acid are 0·7479 and 0·7466; and for carburetted hydrogen 0·5645.

TABLE XXIV.—Transpiration by Capillary H into a 6-pint jar. Barom. 29·63. Temp. 55°.

Gauge barometer in inches.	Air.		Oxygen.		Carbonic oxide.			Carbonic acid.	
	I.	II.	I.	II.	I.	II.	III.	I.	II.
	″	″	″	″	″	″	″	″	″
28·5	0	0	0	0	0	0	0	0	0
26·5	212	212	236	235	214	214	213	175	176
24·5	214	214	237	239	203	205	205	178	177
23·5	110	110	121	120	100	101	101	90	91
From 28·5 to 23·5 inches	536	536	594	594	517	520	519	443	444

Mean Results.

Gauge barometer.		Air.	Carbonic oxide.	Carbonic acid.
From 28·5 to 23·5 inches	Time in seconds ...	536	518·7	443·5
	Time of oxygen=1	0·9023	0·8732	0·7466

5. *Transpiration of different Gases by a Capillary Tube of Copper.*

It appeared desirable to have experiments on the passage of gases through tubes of different materials, in order to ascertain how far the coefficients of transpiration observed are peculiar to glass. After some trials, a capillary tube of copper was constructed, of a fine smooth bore, not wider than an ordinary thermometer tube, and indeed less in diameter than the preceding glass capillary H. This tube was formed by first drilling a cylindrical hole in the axis of a solid copper rod, 4 or 5 inches in length, and extending the latter afterwards by drawing it through a wire-plate. An iron wire, or triplet, was placed within the copper tube and drawn through the wire-plate at the same time, in order to keep the interior surface of the copper tube smooth and uniform. It was necessary to pull out the iron-wire always after the copper was drawn through the plate, to prevent the former being fixed. The iron-wire was then extended somewhat separately, and again introduced into the copper tube, and the operation of drawing out the latter repeated. In this way the copper tube was extended to a length of 11 feet 8 inches. It was found to be perfectly sound and air-tight; and allowed 1 cubic inch of air to pass into a vacuum in 22·12 seconds. Of the iron wire, upon which the copper tube was last drnwn, 92·7 inches weighed 18·30 grains; or 1 inch 0·1974 grain. Taking the specific gravity of iron at 7·7, this gives as the diameter of the copper tube 0·0114 inch, or $\frac{1}{88}$th of an inch. When used as a transpiration tube it was coiled up into circles of about 10 inches in diameter, and the ends joined by soldering to two block-tin tubes provided with screws by which they could be attached to the aspirator-jar and drying tube.

The experiments were conducted precisely in the same way as with a glass tube, except that oil of vitriol was avoided and chloride of calcium only used in the drying tube. The following series of results were obtained with the copper capillary.

TABLE XXV.—Transpiration by a Copper Capillary Tube into a one-pint jar. Barom. 29·97. Temp. 58°.

Gauge barometer in inches.	Air.		Oxygen.		Nitrous oxide.		Carbonic acid.		Air.
	I.	II.	I.	II.	I.	II.	I.	II.	I.
	"	"	"	"	"	"	"	"	"
28	0	0	0	0	0	0	0	0	0
20	234	233	260	261	198	198	199	199	234
12	291	292	324	324	244	244	245	245	292
8	206	205	228	228	170	170	171	170	204
4	333	335	372	373	275	277	276	276	336
2	342	344	387	390	283	285	287	288	344
From 28 to 4 inches ...	1064	1065	1184	1186	887	889	891	890	1066

Mean Results.

Gauge barometer.		Air.	Nitrous oxide.	Carbonic acid.
From 28 to 20 inches...	Time in seconds	233·5	198	199
	Time of oxygen=1...	0·8963	0·7601	0·7639
From 20 to 12 inches...	Time in seconds	291·5	244	245
	Time of oxygen=1...	0·8997	0·7531	0·7561
From 12 to 8 inches ...	Time in seconds	205·5	170	170·5
	Time of oxygen=1...	0·9000	0·7456	0·7478
From 8 to 4 inches......	Time in seconds	334	276	276
	Time of oxygen=1...	0·8966	0·7410	0·7410
From 4 to 2 inches......	Time in seconds	343	284	287
	Time of oxygen=1...	0·8831	0·7310	0·7400
From 28 to 4 inches ...	Time in seconds	1064·5	888	890
	Time of oxygen=1...	0·8983	0·7493	0·7514

It will be observed that the numbers do not differ materially from those obtained with glass tubes, particularly with H. This is a capillary of great resistance, and therefore a deviation from uniformity of ratio may be looked for in the lower part of the scale. A little irregularity in the rate of air, probably accidental, appears in the upper part of the scale ; but as with capillary H, the coefficient for air never varies far from 0·9, at least between 28 and 4 inches.

Carbonic acid and nitrous oxide exhibit the usual parallelism of rate ; but in the upper part of the scale the excess of the coefficient above ·75 is rather considerable. Other experiments were made on the transpiration of carbonic acid into different aspirator jars, as the size of the jar and duration of the experiment appeared to have some influence on the ratios.

Table XXVI.—Transpiration by Copper Capillary into a one-pint jar. Barom. 29·07. Temp. 56°.

Gauge barometer in inches.	Oxygen.		Carburetted hydrogen.	
	I.	II.	I.	II.
28	0″	0″	0″	0″
20	273	274	151	151
12	338	336	186	186
8	237	236	129	130
4	383	385	210	211
2	391	400	214	213
From 28 to 4 inches ...	1231	1231	676	678

Mean Results.

Gauge barometer.		Carburetted hydrogen.
From 28 to 20 inches	Time in seconds	151
	Time of oxygen=1...	0·5521
From 20 to 12 inches	Time in seconds	186
	Time of oxygen=1...	0·5519
From 12 to 8 inches	Time in seconds	129·5
	Time of oxygen=1...	0·5475
From 8 to 4 inches	Time in seconds	210·5
	Time of oxygen=1...	0·5482
From 4 to 2 inches	Time in seconds	213·5
	Time of oxygen=1...	0·5398
From 28 to 4 inches	Time in seconds	677
	Time of oxygen=1...	0·5500

The coefficient obtained for carburetted hydrogen in the preceding experiments never varies much from 0·55, which is the mean between 28 and 4 inches. The result is similar to that given by glass capillary H for the same gas.

Table XXVII.—Transpiration by Copper Capillary into a two-pint jar. Barom. 29·49. Temp. 56°·5.

Gauge barometer in inches.	Air.		Oxygen.		Nitrogen.		Carbonic oxide.		Air.	Hydrogen.	
	I.	II.	I.	II.	I.	II.	I.	II.	III.	I.	II.
28	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″
20	421	419	467	466	405	407	405	404	419	206	205
12	515	514	572	574	501	500	496	498	516	255	254
8	360	363	402	404	351	351	348	348	361	179	179
From 28 to 8 inches...	1296	1296	1441	1444	1257	1258	1249	1250	1296	640	638

Mean Results.

Gauge barometer.		Air.	Nitrogen.	Carbonic oxide.	Hydrogen.
From 28 to 20 inches	Time in seconds	420	406	404·5	205·5
	Time of oxygen=1...	0·9003	0·8703	0·8670	0·4405
From 20 to 12 inches	Time in seconds	514·5	500·5	497	254·5
	Time of oxygen=1...	0·8979	0·8734	0·8673	0·4441
From 12 to 8 inches	Time in seconds	361·5	351	348	179
	Time of oxygen=1...	0·8970	0·8709	0·8635	0·4441
From 28 to 8 inches	Time in seconds	1296	1257·5	1249·5	639
	Time of oxygen=1...	0·8984	0·8717	0·8662	0·4429

The great resemblance which these results bear to those of the last glass capillary is most surprising. The rates of air, nitrogen, carbonic oxide and hydrogen, may be considered as identical with these two capillaries, although they differ in substance, and also in the time of passage, which is slower in the copper capillary than in H, in

the proportion of 22·12 to 15·64. Carbonic oxide, it will be observed, is still sensibly more rapid in its passage than nitrogen.

The experiments in the preceding and all other tables are put down in the order in which they were made. The observation with air is occasionally repeated, to find whether the rate of the capillary remains constant.

Table XXVIII.—Transpiration by Copper Capillary into a three-pint jar. Barom. 29·73. Temp. 57°.

Gauge barometer in inches.	Air.		Oxygen.		Nitrogen.		Hydrogen.		Carbonic acid.	
	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.
28	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0
20	595	595	663	660	575	577	287	287	500	502
12	736	735	818	819	713	713	358	357	616	613
8	516	517	575	577	500	501	251	252	426	428
From 28 to 8 inches...	1847	1847	2056	2056	1788	1791	896	896	1542	1543

Mean Results.

Gauge barometer.		Air.	Nitrogen.	Hydrogen.	Carbonic acid.
From 28 to 20 inches	Time in seconds	595	576	287	501
	Time of oxygen=1...	0·8994	0·8707	0·4339	0·7573
From 20 to 12 inches	Time in seconds	735·5	713	357·5	614·5
	Time of oxygen=1...	0·8986	0·8711	0·4369	0·7507
From 12 to 8 inches	Time in seconds	516·5	500·5	251·5	427
	Time of oxygen=1...	0·8967	0·8689	0·4366	0·7413
From 28 to 8 inches	Time in seconds	1847	1789·5	896	1542·5
	Time of oxygen=1...	0·8984	0·8704	0·4358	0·7502

The preceding results with air and nitrogen might be confounded with those obtained with capillary H. The rate of hydrogen is sensibly faster, while that of carbonic acid is decidedly slower; both gases diverging sensibly from their empirical rates 0·375 and 0·75, on the side of effusion, but the former very slightly.

Table XXIX.—Transpiration by Copper Capillary into a six-pint jar. Barom. 30·14. Temp. 58°.

Gauge barometer in inches.	Air.		Oxygen.		Hydrogen.	
	I.	II.	I.	II.	I.	II.
28	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0
24	......	......	......	614	269	271
20	1139	1139	1268	654	290	290
12	1413	1413	1570	1573	698	699
8	994	993	1109	1110	494	495
From 28 to 8 inches...	3546	3545	3947	3951	1751	1755

Mean Results.

Gauge barometer.		Air.	Hydrogen.
From 28 to 20 inches	Time in seconds	1139	560
	Time of oxygen =1	0·8982	0·4416
From 20 to 12 inches	Time in seconds	1413	698·5
	Time of oxygen =1	0·8991	0·4445
From 12 to 8 inches	Time in seconds	993·5	494·5
	Time of oxygen =1	0·8955	0·4457
From 28 to 8 inches	Time in seconds	3545·5	1753
	Time of oxygen =1	0·8978	0·4439

In these experiments with a large aspirator jar and long times, the rate of air continues very nearly 0·9, and that of hydrogen approaches 0·44. The rates at the upper part of the scale are to be particularly attended to, as most uniform, and as representing pretty nearly transpiration into a vacuum.

TABLE XXX.—Transpiration by Copper Capillary into a six-pint jar.
Barom. 30·23. Temp. 58°·5.

Gauge barometer in inches.	Air.		Oxygen.		Carbonic acid.	
	I.	II.	I.	II.	I.	II.
	59°	59°	59°·25	59°	59°·5	59°·75
28	0″	0″	0″	0″	0″	0″
24	550	550	611	612	469	468
20	590	589	655	655	498	499
12	....	....	1570	1570	1183	1183
8	....	....	1103	1104	824	825
From 28 to 8 inches ...	....	....	3939	3941	2974	2975

Mean Results.

Gauge barometer.		Air.	Carbonic acid.
From 28 to 24 inches...	Time in seconds	550	468·5
	Time of oxygen=1...	0·8994	0 7661
From 24 to 20 inches...	Time in seconds	589·5	498·5
	Time of oxygen=1...	0·9000	0·7610
From 20 to 12 inches...	Time in seconds	....	1183
	Time of oxygen=1...	....	0·7535
From 12 to 8 inches ...	Time in seconds	....	824·5
	Time of oxygen=1...	....	0·7472
From 28 to 8 inches ...	Time in seconds	....	2974·5
	Time of oxygen=1...	....	0·7549

The preceding table contains an experiment on carbonic acid transpired into a large jar. The coefficient of that gas still considerably exceeds 0·75 in the upper part of the scale.

It appears then that the rates of transpiration are similar through glass and copper

tubes, for air, oxygen, nitrogen, hydrogen and carburetted hydrogen; whilst the passage of carbonic acid is subject to a retardation in the upper part of the scale of the copper capillary, by which its rate increases so much as from 0·75 to 0·7661, in the last series of experiments. The rate of carbonic acid indeed exhibits a want of steadiness with this capillary, which is not observed in the other gases enumerated. Thus we find it in the upper part of the scale 0·7639 by Table XXV.; 0·7573 by Table XXVIII.; and 0·7661 by the last table. I may add, that in a preliminary experiment which was made with this gas, and also in an experiment made subsequently to those recorded, and after the tube had been some weeks out of use, so high a coefficient was given for carbonic acid as 0·78. It is impossible to say whether this irregularity is properly referable to the material of the tube, or is peculiar to this individual capillary, as it is the only instrument of the same metal which was used.

The copper tube has no advantage over the glass capillary for experiments on transpiration, while it is liable to the objection that it cannot be used at all with certain gases which have a chemical action on copper, and would tarnish the surface of the tube. The experiments made with it, however, have their value in demonstrating that the rates of transpiration of different gases are essential properties of these gases, and not regulated by the material of the transpiring tube. Indeed there is no more reason to suppose that the coefficient of transpiration of a gas would vary with the substance of the tube, than that the specific gravity of the same gas would be found different according as it was observed in a glass or copper vessel.

6. *Transpiration of different Gases by a Glass Capillary Tube* E.

This was another long capillary glass tube, resembling H, but somewhat shorter. The extreme length of capillary E was 20 feet; it allowed 1 cubic inch of air to pass into a vacuum in 12·03 seconds. One inch of this tube at either end was found to contain 1 grain and 0·94 grain of mercury; the smallest of which admeasurements gives 0·0187 inch as the diameter of the tube; that is, about $\frac{1}{53\cdot5}$th of an inch.

The following table contains a series of experiments on various gases, which were made on one occasion, and in the order in which they are given.

TABLE XXXI.—Transpiration by Capillary E into a six-pint jar.
Barom. 30·340—30·288.

Gauge barometer in inches.	Air.		Oxygen.		Carburetted hydrogen.		Hydrogen.		Carbonic oxide.		Nitrogen.		Nitrous oxide.		Carbonic acid.		Air.	
	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.
	72°	72°	72°	72°·25	72°·75	72°·75	72°·75	72°·75	72°·75	72°·75	72°·75	72°·75	72°·75	72°·75	72°·75	72°·75	72°·75	72°·75
28·5	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″
26·5	153	153	172	170	93	93	75	74	150	149	150	149	129	129	130	130	154	154
24·5	156	156	173	175	97	97	75	76	150	151	151	153	133	133	132	132	158	158
23·5	84	84	92	92	52	50	41	40	80	80	81	80	70	70	70	70	84	84
From 28·5 to 23·5 in.	393	393	437	437	242	240	191	190	380	380	382	382	332	332	332	332	396	396

Mean Results.

Gauge barometer.		Air.	Carburetted hydrogen.	Hydrogen.	Carbonic oxide.	Nitrogen.	Nitrous oxide.	Carbonic acid.	Air.
From 28·5 to 23·5 in.	Time in seconds	393	241	190·5	380	382	332	332	396
	Time of ox. =1	0·8993	0·5515	0·4359	0·8696	0·8741	0·7597	0·7597	0·9062

This table exhibits the transpiration of the gases by E, in the upper part of the scale or into a vacuum nearly, the condition in which the subject is studied with most advantage. The coefficients exhibit a close correspondence with those found by the two preceding capillaries. The number for air is 0·8993 at the beginning, and 0·9062 at the end of the experiments; a variation of rate to which this capillary appeared more liable than the others. The number for nitrogen, 0·8741, again slightly exceeds that for carbonic oxide, 0·8696. Nitrous oxide and carbonic acid have the same number 0·7597, which is in excess compared with 0·75; while the number for hydrogen, 0·4359, is slightly deficient compared with 0·4375. Carburetted hydrogen has the number 0·5515, and is wonderfully constant with all these long capillaries.

As the time of transpiration in these experiments appeared rather short for exact results, a larger aspirator-jar was employed, and the experiment repeated with carbonic acid; air and oxygen being added to give standards of comparison.

Table XXXII.—Transpiration by Capillary E into a nine-pint jar. Barom. 30·136. Temp. 74°·5.

Gauge barometer in inches.	Air.		Oxygen.		Carbonic acid.	
	I.	II.	I.	II.	I.	II.
28·5	0″	0″	0″	0″	0″	0″
26·5	229	229	254	254	190	191
24·5	233	232	259	258	195	195
23·5	121	121	135	135	104	103
From 28·5 to 23·5......	583	582	648	647	489	489

Mean Results.

Gauge barometer.		Air.	Carbonic acid.
From 28·5 to 23·5 inches	Time in seconds	582·5	489
	Time of oxygen=1...	0·8996	0·7550

As the result for carbonic acid differed sensibly from the experiment of the preceding table, it was considered desirable to return to the subject on the following day. In the meantime the barometer had fallen considerably, which accounts for the comparative slowness of transpiration in the following repetition of the last experiments.

Repetition of the last experiments. Barom. 29·616—29·666. Temp. 72°.

Gauge barometer in inches.	Air.		Oxygen.		Carbonic acid.	
	I.	II.	I.	II.	I.	II.
	"	"	"	"	"	"
28·5	0	0	0	0	0	0
26·5	237	236	262	262	196	197
24·5	239	239	266	266	199	202
23·5	129	129	141	141	107	106
From 28·5 to 23·5 inches	605	604	669	669	502	505

Mean Results.

Gauge barometer.		Air.	Carbonic acid.
From 28·5 to 23·5 inches	Time in seconds	604·5	503·5
	Time of oxygen =1...	0·9036	0·7526

The three results for carbonic acid by this capillary are therefore 0·7597, 0·7550 and 0·7526; of which the mean is 0·7558. The coefficient of capillary E for carbonic acid is therefore not so widely different from 0·75 as it at first appeared.

With these large aspirator jars the rise of temperature within the jar during the experiment becomes very small. In the six-pint jar it did not amount to one-quarter of a degree Fahr., and in the nine-pint jar it was altogether insensible.

I have now detailed the results of the transpiration of gases by all the capillaries used except one,—a tube with which a few preliminary experiments in the inquiry were made, not sufficiently precise to merit being recorded. All of these tubes have given the same coefficient of transpiration to each gas, or coefficients closely approximating, although the tubes themselves have varied considerably in their respective dimensions; namely, in diameter, from $\frac{1}{45}$th to $\frac{1}{186}$th of an inch; in length from 2 inches to 22 feet; and from 12 to 70 seconds in the time of transmission of one cubic inch of air into a vacuum. It can be said that no selection of the tubes was made; and their dimensions are in a great measure accidental.

From the agreement in results obtained with tubes so different in dimensions, I consider that a glass tube of any diameter whatever will be found suitable for observations on transpiration, provided a certain length is given to it. If the tube is extremely short, a mere ring, then we know that gases will be transmitted by it into a vacuum according to the law of effusion; oxygen, hydrogen and carbonic acid in times expressed by 1, 0·25 and 1·176 respectively. With the slightest elongation of the tube these ratios are disturbed; the number for hydrogen soon increasing to 0·35 or 0·40, and that for carbonic acid falling to 1, or 0·80, referring both to the time of oxygen always taken as unity. The change with the increase of length is very great at first, but soon falls off, and with a certain length of tube seems to cease altogether. The coefficient of hydrogen is then found to have risen to some number

approaching closely to 0·4375 or 0·44, and the coefficient of carbonic acid to approach closely to 0·75. The coefficient of nitrogen has fallen at the same time from 0·9373 (its coefficient of effusion, that of oxygen being 1) to nearly 0·875.

With this length of the tube, the influence of effusion upon the transpiration rate of the gas has ceased to be sensible.

The action of the tube attains a certain uniformity, at the same time, in another respect. When the tube is deficient in length, the coefficient of the gas varies greatly with the extent of the exhaustion of the vessel into which the gas is flowing; the rate of transpiration inclining most to the rate of effusion at a high degree of exhaustion of the aspirator jar. But the amount of this variation progressively diminishes as the tube becomes longer, till at last the coefficient of transpiration remains nearly if not perfectly constant, whether the aspirator jar be entirely vacuous, or contains already gas of the tension of half an atmosphere, three-fourths or even seven-eighths of an atmosphere.

The tube is now of the length most favourable for experiments of transpiration. Farther addition to the tube appears to have no effect in altering the coefficient of transpiration of air, provided the aspirator jar into which the air passes is vacuous or nearly so; or the coefficient of transpiration into a vacuum appears to remain constant for all greater lengths of the tube. But the extent of the barometric range in the aspirator jar to which the vacuum coefficient is found to apply is gradually limited. Instead of extending over seven-eighths of an atmosphere it may be contracted to an eighth of an atmosphere or less, by greatly lengthening the tube.

The coefficients of transpiration which I have endeavoured to ascertain are properly therefore the relative times of passage of the gases into a vacuum, at the mean atmospheric temperature, or near that temperature.

But even with the most favourable length of the tube, when the aspiration is feeble, and does not exceed 2 or 3 inches of mercury, the rate of transpiration is modified from an interference, which is connected with the excessive resistance of the tube to the passage of the gas. I have not been able to undertake an examination of the nature and extent of this interference, but suppose it to depend upon friction, while the rate of transpiration seems again to depend upon a constitutional difference in the gases themselves.

The theory of the transpirability of gases, which at present appears to me most probable, is that it is a kind of elasticity depending upon the absolute quantity of heat, latent as well as sensible, which different gases contain under the same volume; and therefore that it will be connected more immediately with the specific heat than any other property of the gases.

The only other gases besides those already experimented upon, which could be retained over water, and exposed to the metallic parts of the apparatus without injury, are olefiant gas, nitric oxide and sulphuretted hydrogen; and these were submitted to transpiration with several of the tubes already used. I subjoin the results, although less complete than is desirable, under the head of each gas.

7. *Transpiration of Olefiant Gas.*

TABLE XXXIII.—Transpiration by Capillary H into a six-pint jar. Barom. 29·68. Temp. 59°.

Gauge barometer in inches.	Air.		Olefiant gas.	
	I.	II.	I.	II.
	″	″	″	″
28·5	0	0	0	0
26·5	217	218	124	128
24·5	220	220	130	131
23·5	112	113	66	65
From 28·5 to 23·5 inches ...	549	551	320	324

Transpiration by Capillary H into a one-pint jar.

Gauge barometer in inches.	Air.		Olefiant gas.		Air.
	I.	II.	I.	II.	I.
	″	″	″	″	″
28	0	0	0	0	0
20	184	183	108	108	183
12	227	228	134	134	226
8	163	163	96	96	163
4	265	265	153	151	265
2	260	264	149	149	260
From 28 to 2 inches	1099	1103	640	638	1097

		Air.	Olefiant gas.
From 28·5 to 23·5 inches	Time in seconds	550	322
	Time of air=1	....	0·5854
	Time of oxygen=1....	....	0·5268

		Air.	Olefiant gas.
From 28 to 2 inches......	Time in seconds	1099·7	639
	Time of air=1	....	0·5810
	Time of oxygen=1 ...	....	0·5229

TABLE XXXIV.—Transpiration by Capillary H (with cupped ends) into a six-pint jar. Barom. 30·2. Temp. 52°.

Gauge barometer in inches.	Air.		Carburetted hydrogen.		Olefiant gas.		Air.	$90C_4H_4+10CO$.		Air.	
	I.	II.	I.	II.	I.	II.	I.	I.	II.	I.	II.
	″	″	″	″	″	″	″	″	″	″	″
28·5	0	0	0	0	0	0	0	0	0	0	0
26·5	206	207	127	126	120	118	207	126	126	207	207
24·5	208	208	127	128	119	121	208	126	127	209	209
23·5	106	106	64	65	61	61	106	64	64	104	104
From 28·5 to 23·5 inches ...	520	521	318	319	300	300	521	316	317	520	520

Mean Results.

Gauge barometer.		Air.	Carburetted hydrogen.	Olefiant gas.	$90C_4H_4+10CO$.	Air.
From 28·5 to 23·5 inches	Time in seconds	521·5	318·	300	316·5	
	Time of air=1	....	0·6118	0·5763	0·6080	
	Time of oxygen=1....	....	0·5506	0·5186	0·5472	

The results for olefiant gas can be considered only as approximative from the circumstance that the gas was always contaminated by a small quantity of carbonic oxide, varying from 3 to 5 per cent., and a sensible trace of the dense gas or vapour, to which allusion has already been made. Both impurities would tend to raise the number for olefiant gas; ten per cent. of carbonic oxide purposely added to that gas, raising its number from 0·5186 to 0·5472. The calculated mean rate of the last mixture is 0·5513, taking the rate of carbonic oxide at 0·8700, and that of olefiant gas at 0·5186. If the true coefficient for olefiant gas should be a whole number, it may be expected to be 0·5, or exactly one-half of the rate of oxygen.

8. *Transpiration of Nitric Oxide.*

Table XXXV.—Transpiration by Capillary E into a one-pint jar. Barom. 30·45. Temp. 52°.

Gauge barometer in inches.	Air.	Nitric oxide.		Oxygen.	Air.
	I.	I.	II.	I.	I.
28	0″	0″	0″	0″	0″
20	135	135	131	149	135
12	167	162	162	186	169
8	118	115	115	133	118
4	189	183	184	206	188
2	192	184	188	219	195
From 28 to 4 inches ...	609	595	592	674	610

Mean Results.

Gauge barometer.		Air.	Nitric oxide.	Air.
From 28 to 4 inches......	Time in seconds	609	593·5	610
	Time of oxygen=1 ...	0·9035	0·8805	0·9035

TABLE XXXVI.—Transpiration by Capillary E into a two-pint jar. Barom. 30·08. Temp. 60°.

Gauge barometer in inches.	Nitrogen.			Nitric oxide.		Oxygen.	
	I.	II.	III.	I.	II.	I.	II.
28	0″	0″	0″	0″	0″	0″	0″
20	231	232	......	237	235	266	267
12	286	287	286	288	287	327	328
8	200	200	202	203	206	227	227
4	320	317	320	313	312	363	364
2	314	320	316	311	315	361	361
From 28 to 2 inches...	1351	1356	......	1352	1355	1544	1547

Mean Results.

Gauge barometer.		Nitrogen.	Nitric oxide.
From 28 to 12 inches	Time in seconds	517·83	523·5
	Time of oxygen=1...	0·8717	0·8815
From 12 to 4 inches	Time in seconds	519·7	517
	Time of oxygen=1...	0·8801	0·8755
From 4 to 2 inches	Time in seconds	316·7	313
	Time of oxygen=1...	0·8772	0·8670
From 28 to 2 inches	Time in seconds	1354·2	1353·5
	Time of oxygen=1...	0·8768	0·8764

The number for nitric oxide (NO_2) approaches very closely to that of nitrogen, if it does not actually coincide with that number; yet the specific gravities of these two gases are different, that of nitric oxide being 1·0405, air =1; or 0·9375, oxygen =1; the mean between the densities of oxygen and nitrogen gases. It would appear from this that the coefficients of transpiration of gases are less various than their specific gravities. In conducting experiments with this gas, the surface of the mercury in the gauge tube is tarnished, which causes it to adhere to the glass and descend irregularly, so that the observations want the usual uniformity, as seen in both tables. When a few drops of water were placed above the mercury in the gauge barometer, its descent became more regular. This gas acted inconveniently in another way, by forming a solid compound with the oil in the cylinders, and thus clogging the action of the air-pump.

9. *Transpiration of Sulphuretted Hydrogen.*

TABLE XXXVII.—Transpiration by Capillary H into a one-pint jar. Barom. 29·89. Temp. 59°.

Gauge barometer in inches.	Air.		Sulphuretted hydrogen.			Air.
	I.	II.	I.	II.	III.	I.
28	0″	0″	0″	0″	0″	0″
20	180	180	122	123	121	178
12	226	224	156	158	153	225
8	155	158	108	109	110	156
4	262	257	177	174	173	258
2	253	256	175	173	173	255
From 28 to 2 inches...	1076	1075	738	732	730	1072

Mean Results.

Gauge barometer.		Sulphuretted hydrogen.
From 28 to 12 inches	Time in seconds	276
	Time of air... =1...	0·6814
	Time of oxygen=1...	0·6132
From 12 to 4 inches	Time in seconds	283·66
	Time of air... =1...	0·6738
	Time of oxygen=1...	0·6060
From 4 to 2 inches	Time in seconds	173·66
	Time of air... =1...	0·6825
	Time of oxygen=1...	0·6142
From 28 to 2 inches	Time in seconds	733·3
	Time of air... =1...	0·6818
	Time of oxygen=1...	0·6136

TABLE XXXVIII.—Transpiration by Capillary H into a six-pint jar. Barom. 29·98. Temp. 59°.

Gauge barometer in inches.	Air.		Sulphuretted hydrogen.				Air.			
	I.	II.	I.	II.	III.	IV.	I.	II.	III.	IV.
28·5	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″
26·5	206	203	140	140	140	141	206	203	203	205
24·5	207	209	143	147	146	148	216	214	217	215
23·5	107	109	77	75	77	75	108	109	109	111
From 28·5 to 23·5 inches	520	521	360	362	363	364	530	526	529	531

Mean Results.

Gauge barometer.		Sulphuretted hydrogen.
From 28·5 to 23·5 inches	Time in seconds	362·25
	Time of air... =1...	0·6846
	Time of oxygen=1...	0·6161

The experiments with this gas indicate a number above 0·60 for its coefficient of transpiration; 0·625 is 5-8ths of oxygen, while the result of Table XXXVIII., which is the more valuable of the two, is 0·6161. But this gas is likely to vary sensibly in its coefficient with different capillaries, like carbonic acid; and both its physical and chemical properties oppose difficulties to obtaining a correct result. The rate of air following this gas is made very sensibly slower in the last table; indeed the rate of the capillary appears to be permanently altered, possibly from the deposition of sulphur from the gas.

[I shall add, in an Appendix to this paper, a series of observations on the transpiration of gaseous mixtures, which appear to warrant the following conclusions:—

It appears from Tables XLII. and XLIII., that mixtures of oxygen and nitrogen in all proportions maintain a rate which is sensibly the arithmetical mean rate of the two gases.

From Tables XLIV. and XLV., that the rates of mixtures of oxygen and carbonic oxide are also uniform, but that mixtures of carbonic oxide and hydrogen deviate greatly from the mean, inclining always to that of the heavier gas.

In Tables XLVI. and XLVII., that the mixtures of oxygen and carbonic acid maintain the mean rate; and that mixtures of carburetted hydrogen and hydrogen deviate greatly from the mean, always inclining to the rate of the slower gas.

Tables from XLVIII. to LIII. inclusive, exhibit the transpiration of hydrogen mixed with various other gases, particularly nitrogen, oxygen, carbonic acid, nitrous oxide, and nitric oxide; and Tables LIV. and LV. contain the results of the transpiration of mixtures of carburetted hydrogen with oxygen and with hydrogen. It appears that while all the other gases tried appeared to maintain their usual rates of transpiration in a state of mixture, those of carburetted hydrogen and hydrogen are greatly altered; and when the proportion of the latter gas is not more than from 5 to 15 per cent., its rate becomes as slow as the densest gas with which it is mixed; the deviation from the mean in hydrogen mixtures being relatively greatest when one of the gases is present in a small proportion. With an addition of so much as 25 per cent. of hydrogen, carburetted hydrogen, carbonic acid and nitrous oxide continue to be transpired in sensibly the same times as when pure and unmixed. Hydrogen is then transpired of course as slowly as the other gas with which it is mixed, although the time of hydrogen alone is 0·44, while that of carburetted hydrogen is 0·55, and of carbonic acid and nitrous oxide 0·75. Indeed small additions of hydrogen, such as 5 or 10 per cent., made to carburetted hydrogen, appear to prolong the time of transpiration; and what is very curious, raise the time of the mixture to the empirical number of pure carburetted hydrogen, namely, 0·5625 (Table XLVII.). A slight retardation of the same kind may also be perceived in the similar carbonic acid mixtures. The transpiration-time of equal volumes of hydrogen and carbonic acid is 0·7339, or very little less than that of pure carbonic acid.

Carbonic oxide and nitric oxide, with equal admixtures of hydrogen, correspond as closely in their times as when pure, as will be seen on comparing together the results of Tables XLV. and LIII. A similar apparent rectification of the time of nitric oxide will be observed, in the last of these tables, to be effected by the addition of 5 per cent. of hydrogen to that gas, as was remarked above of carburetted hydrogen; the time of 100 NO_2 being 0·8661, that of 95 NO_2+5H is found 0·8788; while the empirical coefficient for nitric oxide is the same as that of nitrogen, namely, 0·8750, or 0·8785, adopting REGNAULT's density of the latter gas.

It appears that the time of carburetted hydrogen is sensibly increased by the addition of oxygen, at least when the proportion of the latter gas amounts to or exceeds 25 per cent. of the mixture (Table LIV.).

The times of transpiration of the hydrogen mixtures, which have been most minutely observed, namely, those of hydrogen with oxygen, with air, and with carbonic acid, are exhibited by the curves of Plate XXXV. These curves start from a common point 44, the time of pure hydrogen, and terminate respectively with the times of oxygen 100, of air 90, and of carbonic acid 75.

It would be premature to enter at present upon any discussion of these results; for the full elucidation of the transpiration of mixed gases, must await, I believe, the further extension of our knowledge of the laws of gaseous diffusion. Nov. 1846.]

APPENDIX.

Tables of the observed Transpiration of Gaseous Mixtures.

TABLE XLII.—Transpiration by Capillary E into a one-pint jar. Barom. 29·55. Temp. 53°.

Gauge barometer in inches.	Air.		Oxygen.		97·5O+2·5N.		95O+5N.		90O+10N.		75O+25N.		66·6O+33·3N.		Oxygen.
	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	I.
28	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″
20	142	143	158	158	......	......	157	158	156	157	153	153	151	151	157
12	176	175	196	195	353	353	194	194	192	192	190	189	187	187	195
8	123	123	137	138	137	137	137	136	136	136	133	134	131	132	137
4	197	197	222	220	220	219	220	219	218	216	214	214	211	211	220
2	199	197	221	222	222	223	220	221	219	221	218	219	212	212	222
From 28 to 2 inches.	837	835	934	933	932	932	928	928	921	922	908	909	892	893	931

Mean Results.

Gauge barometer.		Air.	97·5O+2·5N.	95O+5N.	90O+10N.	75O+25N.	66·6O+33·3N.	Oxygen.
From 28 to 2 inches.	Time in seconds	836	932	928	921·5	908·5	892·5	
	Time of oxygen=1...	0·8955	0·9984	0·9941	0·9871	0·9734	0·9550	
	Calculated mean......	....	0·9969	0·9938	0·9875	0·9688	0·9583	

TABLE XLIII.—Transpiration by Capillary E into a one-pint jar. Barom. 29·81. Temp. 54°.

Gauge barometer in inches.	Air.		50N+50O.		Oxygen.	66·6N+33·3O.	75N+25O.	90N+10O.	95N+5O.	97·5N+2·5O.	Nitrogen.	Air.
	I.	II.	I.	II.	I.	I.	I.	I.	I.	I.	I.	I.
28	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″
20	140	141	147	147	157	143	142	139	139	139	138	145
12	174	173	181	181	193	177	176	172	170	170	169	175
8	122	123	128	128	137	125	123	121	120	120	119	124
4	196	196	204	204	219	199	198	193	192	193	192	198
2	197	196	208	207	222	204	201	196	196	199	194	198
From 28 to 2 inches.	829	829	868	867	928	848	840	821	817	821	812	840

Mean Results.

Gauge barometer.		Air.	50N+50O.	66·6N+33·3O.	75N+25O.	90N+10O.	95N+5O.	97·5N+2·5O.	Nitrogen.	Air.
From 28 to 2 inches	Time in seconds ...	829	867·5	848	840	821	817	821	812	840
	Time of oxygen=1	0·8933	0·9348	0·9138	0·9051	0·8847	0·8804	0·8847	0·8750	0·9052
	Calculated mean...	....	0·9375	0·9167	0·9062	0·8875	0·8812	0·8805	0·8789	

Table XLIV.—Transpiration by Capillary E into a one-pint jar. Barom. 29·69. Temp. 54°.

Gauge barometer in inches.	Oxygen.	Carbonic oxide.	97·5CO+2·5O.	95CO+5O	90CO+10O.	75CO+25O.	Air.	Oxygen.
	I.	I.	I.	I.	I.	I.	I.	I.
28	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0
20	157	137	139	138	140	142	143	158
12	195	169	169	170	172	176	175	196
8	137	118	120	120	120	124	123	138
4	219	192	191	192	194	198	197	221
2	221	190	192	193	202	202	199	221
From 28 to 4 inches ...	708	616	619	620	626	640	638	713

Mean Results.

Gauge barometer.		Carbonic oxide.	97·5CO+2·5O.	95CO+5O.	90CO+10O.	75CO+25O.	Air.	Oxygen.
From 28 to 4 inches...	Time in seconds ...	616	619	620	626	640	638	
	Time of oxygen=1.	0·8701	0·8743	0·8757	0·8842	0·9040	0·9011	
	Calc. mean	....	0·8733	0·8765	0·8830	0·9026		

Table XLV.—Transpiration by Capillary E into a one-pint jar. Barom. 30·18. Temp. 52°.

Gauge barometer in inches.	Air.	Carbonic oxide.	66·7CO+33·3O.	50CO+50O.	66·7O+33·3CO.	75O+25CO.	Oxygen.	95CO+5H.	90CO+10H.	75CO+25H.	92·5CO+7·5H.	Air.	Hydrogen.
	I.	I.	I.	I.	I.	I.	I.	I.	I.	I.	I.	I.	I.
28	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0
20	137	132	140	143	146	148	152	133	132	128	132	137	78
12	169	164	172	177	181	183	189	164	163	159	163	170	84
8	119	116	122	125	128	130	133	115	116	113	115	121	59
4	192	185	195	200	206	205	215	184	185	181	185	193	95
2	193	188	201	205	209	204	219	190	191	181	191	201	100
From 28 to 4 inches...	617	597	629	645	661	666	689	596	596	581	595	621	316

Mean Results.

Gauge barometer.		Air.	Carbonic oxide.	66·7CO+33·3O.	50CO+50O.	66·7O+33·3CO.	75O+25CO.	95CO+5H.	90CO+10H.	75CO+25H.	92·5CO+7·5H.	Air.	Hydrogen.
From 28 to 4 inches.	Time in sec....	617	597	629	645	661	666	596	596	581	595	621	316
	Time of ox.=1	0·8905	0·8664	0·9129	0·9361	0·9593	0·9666	0·8650	0·8650	0·8432	0·8635	0·9013	0·4586
	Calc. mean, A*.	....	....	0·9109	0·9332	0·9554	0·9666	0·8046	0·8256	0·7644	0·8358		
	Calc. mean, B†.	....	....	....	....	....	....	0·8450	0·8237	0·7848	0·8344		

* Mean with the number for hydrogen actually observed.

† Mean with the number 0·44 as the coefficient of hydrogen. These last results are most to be depended upon, as the rate of the hydrogen alone is often raised by a slight impurity, of which the effect would become much less sensible in the mixtures containing that gas.

Table XLVI.—Transpiration by Capillary E into a one-pint jar. Barom. 29·94. Temp. 56°.

Gauge barometer in inches.	Air.	Oxygen.	Carbonic acid.	$97·5CO_2+2·5O$.	$95CO_2+5O$.	$90CO_2+10O$.	$75CO_2+25O$.	$50CO_2+50O$.	Carbonic acid.
	I.	I.	I.	I.	I.	I.	I.	I.	I.
28	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0
20	139	155	118	119	....	120	127	136	117
12	172	192	144	145	266	149	156	168	145
8	......	135	101	102	102	104	109	118	102
4	315	218	161	163	163	166	174	188	161
2	198	218	161	162	163	166	175	190	162
From 28 to 2 in.	824	918	685	691	694	705	741	800	687

Mean Results.

Gauge barometer.		Air.	Carbonic acid.	$97·5CO_2+2·5O$.	$95CO_2+5O$.	$90CO_2+10O$.	$75CO_2+25O$.	$50CO_2+50O$.	Carbonic acid.
From 28 to 2 inches	Time in seconds ...	824	685	691	694	705	741	880	687
	Time of oxygen=1	0·8976	0·7461	0·7538	0·7559	0·7679	0·8071	0·8714	0·7467
	Calculated mean...	....	....	0·7524	0·7588	0·7715	0·8096	0·8730	

Table XLVII.—Transpiration by Capillary E into a one-pint jar. Barom. 29·61. Temp. 54°.

Gauge barometer in inches.	Carburetted hydrogen.	$90CH_2+10H$.	$95CH_2+5H$.	$97·5CH_2+2·5H$.	Hydrogen.	Oxygen.	$90O+10CO_2$.	$75O+25CO_2$.	$95O+5CO_2$.	$97·5O+2·5CO_2$.	Carbonic acid.	$82·5CH_2+17·5H$.
	I.	I.	I.	I.	I.	I.	I.	I.	I.	I.	I.	I.
28	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0	″ 0
20	87	89	89	87	71	158	154	149	155	156	119	88
12	107	110	109	107	88	194	189	183	192	193	147	109
8	....	76	76	75	61	137	133	128	134	136	102	75
4	195	123	123	120	98	218	214	206	217	218	163	122
2	121	124	123	122	102	224	219	211	222	224	166	123
From 28 to 4 in.	389	398	397	389	318	707	690	666	698	703	531	394

Mean Results.

Gauge barometer.		Carburetted hydrogen.	$90CH_2+10H$.	$95CH_2+5H$.	$97·5CH_2+2·5H$.	Hydrogen.	$90O+10CO_2$.	$75O+25CO_2$.	$95O+5CO_2$.	$97·5O+2·5CO_2$.	Carbonic acid.	$82·5CH_2+17·5H$.
From 28 to 4 in.	Time in seconds	389	398	397	389	318	690	666	698	703	531	394
	Time of ox. =1	0·5544	0·5629	0·5615	0·5502	0·4497	0·9759	0·9420	0·9872	0·9943	0·7510	0·5572
	Calc. mean, A*.	....	0·5439	0·5266	0·5409	....	0·9750	0·9375	0·9875	0·9937	....	0·5360
	Calc. mean, B†.	....	0·5429	0·5486	0·5515	....	....	....	....	....	....	0·5343

* Mean with the number for hydrogen actually observed.

† Mean with the number 0·44 as the coefficient of hydrogen. These last results are most to be depended upon, as the rate of the hydrogen alone is often raised by a slight impurity, of which the effect would become much less sensible in the mixtures containing that gas.

TABLE XLVIII.—Transpiration by Capillary E into a one-pint jar. Barom. 29·63. Temp. 52°.

Gauge barometer in inches.	Air.		Air.	Oxygen.		97·5O+2·5H.		95O+5H.		90O+10H.		75O+25H.		Hydrogen.	
	I.	II.	I.	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.	I.	II.
28	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″
20	141	142	142	158	158	157	157	157	157	156	156	153	153	70	70
12	177	176	176	195	195	194	195	195	194	194	194	189	189	87	87
8	122	122	122	137	136	137	136	136	137	135	136	133	132	62	62
4	197	196	196	219	219	218	219	218	219	217	217	213	213	99	99
2	195	196	199	219	221	219	217	223	221	221	221	216	215	100	100
From 28 to 2 inches	832	832	835	928	929	925	924	929	928	923	924	904	902	418	418

Mean Results.

Gauge barometer.		Air.	97·5O+2·5H.	95O+5H.	90O+10H.	75O+25H.	Hydrogen.
From 28 to 2 inches	Time in seconds	833	924·5	928·5	923·5	903	418
	Time of oxygen = 1...	0·8971	0·9957	1·000	0·9946	0·9724	0·4502
	Calculated mean A....	....	0·9862	0·9725	0·9450	0·8625	
	Calculated mean B....	....	0·9860	0·9720	0·9440	0·8600	

TABLE XLIX.—Transpiration by Capillary E into a one-pint jar. Barom. 29·57. Temp. 55°.

Gauge barometer in inches.	Air.	Hydrogen.	50H+50N.	25H+75CO$_2$.	10H+90CO$_2$.	25H+75CH$_2$.	Carburetted hydrogen.	Oxygen.	Nitrogen.	Air.
	I.	I.	I.	I.	I.	I.	I.	I.	I.	I.
28	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″
20	143	71	127	120	120	90	88	158	138	142
12	175	87	156	146	147	109	108	195	170	176
8	......	62	105	103	103	76	75	136	120	122
4	321	99	181	166	164	122	121	221	189	199
2	194	99	173	159	158	122	118	213	191	196
From 28 to 4 inches	639	319	569	535	534	397	392	710	617	639

Mean Results.

Gauge barometer.		Air.	Hydrogen.	50H+50N.	25H+75CO$_2$.	10H+90CO$_2$.	25H+75CH$_2$.	Carburetted hydrogen.	Nitrogen.	Air.
From 28 to 4 inches	Time in seconds ...	639	319	569	535	534	397	392	617	639
	Time of oxygen = 1	0·9000	0·4493	0·8014	0·7535	0·7521	0·5591	0·5521	0·8690	0·9000
	Calculated mean A.	....	....	0·6590	0·6723	0·7172	0·5264			
	Calculated mean B.	....	....	0·6545	0·6702	0·7163	0·5240			

Table L.—Transpiration by Copper Capillary into a three-pint jar. Barom. 30·1. Temp. 61°.

Gauge barometer in inches.	Air.		Hydrogen.		95H+5 Air.		90H+10 Air.	75 H+25 Air.	H25+75 Air.
	I.	II.	I.	II.	I.	II.	I.	I.	I.
	61°·25	61°·25	61°·5	61°·5	61°·75	61°·75	61°·75	61°·75	61°·75
28	0″	0″	0″	0″	0″	0″	0″	0″	0″
24	286	285	139	140	168	165	183	227	280
20	301	302	148	148	178	177	196	241	296
12	729	731	358	360	431	424	474	581	705
8	515	512	254	257	306	300	343	412	507
	61°·75	61°·75	62°	62°	62°	62°	62°	62°	62°
From 28 to 8 inches	1831	1830	899	905	1083	1066	1196	1461	1788

Transpiration by Copper Capillary into a three-pint jar. Barom. 30·19. Temp. 61°·5.

Gauge barometer in inches.	Air.		50H+50 Air.	10H+90 Air.	5H+95 Air.
	I.	II.	I.	I.	I.
	61°·5	61°·5	61°·5	61°·5	61°·5
28	0″	0″	0″	0″	0″
24	284	284	258	280	282
20	302	302	274	298	300
12	727	728	662	721	724
8	514	515	471	510	514
	62°	62°	62°	62°	62°
From 28 to 8 inches	1827	1829	1665	1809	1820

Mean Results.

Gauge barometer.		Air.	Hydrogen.	95H+5 Air.	90H+10 Air.	75H+25 Air.	25H+75 Air.
From 28 to 8 in.	Time in seconds ...	1803·5	902	1074·5	1196	1461	1788
	Time of air =1 ...	....	0·4927	0·5869	0·6534	0·7987	0·9767
	Time of oxygen=1	....	0·4434	0·5282	0·5880	0·7488	0·8790
	Calculated mean ...	....	....	0·4630	0·4860	0·5500	0·7850

		Air.	50H+50 Air.	10H+90 Air.	5H+95 Air.
From 28 to 8 in.	Time in seconds ...	1828	1665	1809	1820
	Time of air =1 ...	....	0·9108	0·9876	0·9956
	Time of oxygen=1	....	0·8197	0·8888	0·8960
	Calculated mean ...	....	0·6700	0·8540	0·8770

TABLE LI.—Transpiration by Capillary E into a one-pint jar. Barom. 29·89. Temp. 54°.

Gauge barometer in inches.	$97·5H+2·5CO_2$.	$95H+5CO_2$.	$90H+10CO_2$.	$75H+25CO_2$.	$50H+50CO_2$.	Carbonic acid.	Oxygen.	Hydrogen.	Air.
	I.	I.	I.	I.	I.	I.	I.	I.	I.
	″	″	″	″	″	″	″	″	″
28	0	0	0	0	0	0	0	0	0
20	77	79	88	105	114	118	156	68	142
12	95	99	110	130	142	145	192	85	173
8	67	69	77	92	99	102	136	60	121
4	109	113	125	148	160	162	217	97	195
2	111	115	127	150	161	161	220	98	201
From 28 to 2 in.	459	475	527	625	676	688	921	398	832

Mean Results.

Gauge barometer.		$97·5H+2·5CO_2$.	$95H+5CO_2$.	$90H+10CO_2$.	$75H+25CO_2$.	$50H+50CO_2$.	Carbonic acid.	Hydrogen.	Air.
From 28 to 8 in.	Time in seconds	459	475	527	625	676	688	398	832
	Time of ox. =1	0·4983	0·5157	0·5722	0·6786	0·7339	0·7470	0·4321	0·9033
	Calculated mean	0·4402	0·4484	0·4648	0·5113	0·6455			

TABLE LII.—Transpiration by Capillary E into a one-pint jar. Barom. 30·39. Temp. 52°.

Gauge barometer in inches.	Air.	Oxygen.	Nitrous oxide.	75NO+25H.	90NO+10H.	Air.
	I.	I.	I.	I.	I.	I.
	″	″	″	″	″	″
28	0	0	0	0	0	0
20	136	152	114	114	114	135
12	168	187	141	141	141	168
8	119	132	99	99	98	119
4	189	212	157	159	158	190
2	198	222	159	162	159	196
From 28 to 4 inches...	612	683	511	513	511	612

Mean Results.

Gauge barometer.		Air.	Nitrous oxide.	75NO+25H.	90NO+10H.	Air.
From 28 to 4 inches	Time in seconds ...	612	511	513	511	612
	Time of oxygen=1	0·8960	0·7481	0·7510	0·7481	0·8960
	Calc. mean, A. ...	....	....	0·6757	0·7292	
	Calc. mean, B. ...					

Table LIII.—Transpiration by Capillary E into a one-pint jar. Barom. 30·62. Temp. 52°.

Gauge barometer in inches.	Air.	Oxygen.	Hydrogen.	Nitric oxide.		$95NO_2+5H$.
	I.	I.	I.	I.	II.	I.
28	0″	0″	0″	0″	0″	0″
20	133	149	66	130	129	130
12	167	184	83	161	158	163
8	117	131	59	114	112	115
4	189	212	95	183	184	186
2	192	214	97	183	181	184
From 28 to 4 inches ...	606	676	303	588	583	594

Gauge barometer in inches.	$90NO_2+10H$.	$75NO_2+25H$.	$50NO_2+50H$.	$25NO_2+75H$.	Air.
	I.	I.	I.	I.	I.
28	0″	0″	0″	0″	0″
20	128	125	119	106	134
12	160	157	150	132	168
8	113	112	117	95	120
4	181	180	170	151	192
2	181	185	179	153	193
From 28 to 4 inches ...	582	574	556	484	614

Mean Results.

Gauge barometer.		Air.	Hydrogen.	Nitric oxide.	$95NO_2+5H$.
From 28 to 4 inches	Time in seconds	606	303	585·5	594
	Time of oxygen=1...	0·8964	0·4482	0·8661	0·8788
	Calc. mean, A.........	....	....	....	0·8452
	Calc. mean, B.........	....	....	....	0·8447
		$90NO_2+10H$.	$75NO_2+25H$.	$50NO_2+50H$.	$25NO_2+75H$.
From 28 to 4 inches	Time in seconds	582	574	556	484
	Time of oxygen=1...	0·8609	0·8491	0·8224	0·7159
	Calc. mean, A.........	0·8243	0·7616	0·6571	0·5527
	Calc. mean, B.........	0·8234	0·7596	0·6530	0·5465
		Air.			
From 28 to 4 inches	Time in seconds	614			
	Time of oxygen=1...	0·9082			

TABLE LIV.—Transpiration by Capillary E into a one-pint jar. Barom. 29·71. Temp. 55°.

Gauge barometer in inches.	Oxygen.	Carburetted hydrogen.	$97·5CH_2+2·5O$.	$95CH_2+5O$.	$90CH_2+10O$.	$75CH_2+25O$.	$50CH_2+50O$.	Air.
	I.	I.	I.	I.	I.	I.	I.	I.
28	0″	0″	0″	0″	0″	0″	0″	0″
20	157	91	91	92	94	109	127	141
12	195	109	112	114	117	134	157	174
8	136	77	79	79	81	94	110	122
4	219	122	126	127	131	151	177	195
2	224	124	127	129	133	153	180	200
From 28 to 4 inches	707	399	408	412	423	488	571	632

Mean Results.

Gauge barometer.	Carburetted hydrogen.	$97·5CH_2+2·5O$.	$95CH_2+5O$.	$90CH_2+10O$.	$75CH_2+25O$.	$50CH_2+50O$.	Air.
From 28 to 4 inches. Time in seconds.	399	408	412	423	488	571	632
Time of ox.=1...	0·5629	0·5770	0·5827	0·5983	0·6902	0·8076	0·8939
Calc. mean.......	....	0·5734	0·5838	0·6062	0·6718	0·7814	

TABLE LV.—Transpiration by Capillary E into a one-pint jar. Barom. 29·43. Temp. 55°.

Gauge barometer in inches.	Air.	Hydrogen.	$97·5H+2·5CH_2$.	$95H+5CH_2$.	$90H+10CH_2$.	$75H+25CH_2$.	$50H+50CH_2$.	Carburetted hydrogen.	Hydrogen.	Oxygen.
	I.	I.	I.	I.	I.	I.	I.	I.	I.	I.
28	0″	0″	0″	0″	0″	0″	0″	0″	0″	0″
20	144	73	75	77	79	84	88	88	74	160
12	176	91	93	94	98	105	109	108	92	197
8	124	64	65	66	68	73	76	76	65	138
4	198	103	105	107	111	119	122	121	105	222
2	201	105	107	109	113	120	126	123	106	225
From 28 to 4 inches ...	642	331	338	344	356	381	395	393	336	717

Mean Results.

Gauge barometer.	Air.	Hydrogen.	$97·5H+2·5CH_2$.	$95H+5CH_2$.	$90H+10CH_2$.	$75H+25CH_2$.	$50H+50CH_2$.	Carburetted hydrogen.	Hydrogen.
From 28 to 4 inches... Time in sec....	642	331	338	344	356	381	395	393	336
Time of ox.=1	0·8955	0·4616	0·4714	0·4797	0·4965	0·5313	0·5596	0·5481	0·4686
Calc. mean, A	....	....	0·4705	0·4725	0·4765	0·4884	0·5083		
Calc. mean, B.	....	....	0·4427	0·4454	0·4508	0·4670	0·4940		